EX ✣ UNO ✣ DISCE ✣ OMNES ✣

CRYSTAL MODELS

A SYSTEM

FOR

THE CONSTRUCTION

OF

CRYSTAL MODELS

ON THE TYPE OF AN ORDINARY PLAIT;

EXEMPLIFIED BY THE FORMS BELONGING TO THE SIX AXIAL SYSTEMS IN CRYSTALLOGRAPHY.

[by John Gorham.]

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NEW YORK: 12, CORTLANDT STREET.
1888.

PREFACE.

It is now some forty years since I had the honour of demonstrating before the Royal Society in London "*A System for the Construction of Crystal Models projected on Plane Surfaces.*" These figures folded into the required form, and subsided into a level at pleasure—they were easily moulded into shape by bringing their edges into apposition with the fingers, and were as easily transferred from place to place when flattened in a portfolio—they constituted, in short, an extension of the plan used in modern mathematical treatises for extemporising models of the five regular or Platonic solids. At that period, besides diagrams in isometric perspective, which are as necessary now as they were then, models in wood were much in vogue. They were used by Dr. Pareira in his lectures on the Polarisation of Light before the Pharmaceutical Society of Great Britain. Phillips, in the second edition of his 'Introduction to Mineralogy,' recommends the use of models cut in box-wood, and observes that "they could be had at one guinea each, while complete sets could be procured at the price of £16 the set"; at this rate the study of crystallography became somewhat expensive. In modern times it has been found possible to arrange the many thousand different known crystals in *six systems*, to each of which belongs a number of forms having some property in common. Each system consists of a skeleton model of three or four rods of wood, wire, or glass; these rods are called axes, round which the forms can be symmetrically built up. Upon these axes it is proposed, in the first place, to find the faces of the required model by direct measurement (or recourse may be had to Spherical Trigonometry, as the case may be), and in the next place, to build them up into a model by a process which it is believed has not been hitherto attempted. It consists in taking an ordinary plait of three or four rushes, defining its intersections in numerical order, and thus eliminating the *type* on which every model is constructed. By strictly adhering to the type it was found, moreover, that those solids which were confessedly irregular and most difficult to understand—those, for instance, belonging to the *doubly oblique system*—were made with the same facility as the cube itself.

Considering how the zones in crystals approximate in appearance to the ideal plait, it is singular that this method of making models should so long have escaped notice. The first intimation of the possibility of forming a crystal model in this way suggested itself in the case of the *rhombic dodecahedron*, a solid bounded by twelve rhombs, and characterised by exceeding elegance of form—some of the smaller specimens of garnet constituting the most æsthetic "things of beauty" in all mineralogy. On a careful examination of one of these crystals, its faces appeared to be arranged in narrow strips, which could be traced round the form in four different directions, and seemed to cut each other in their course as if they intersected. It became

difficult not to realise the practicability of using strips of paper—of crossing them just as these zones appeared to be crossed in a real crystal, and of intertwining them as in a plait. Four narrow strips of paper were taken accordingly, each being composed of similar rhombs placed together at their opposite edges, after crossing and recrossing repeatedly, a rough model of the form was eventually obtained. The ability to make a single solitary model, however, and that by a mere hap-hazard, was not altogether encouraging. On reconsidering the matter, it became evident that the definite arrangement of the parts in a plait could be at once utilised by finding the numerical order in which its intersections occurred. This formed a clue to the whole. The idea, when practically worked out, fulfilled my most sanguine expectations, as shown by the results which are recorded in the following pages.

Compared with others, the advantages resulting from this method become most strikingly apparent. The models are built up into form in a few seconds, and it is worthy of notice that, owing to the plaiting process being well nigh instinctive, the manipulations after a short trial become almost automatic; the eyes may be closed—the attention diverted—yet the required solid meanwhile may be growing into existence. The forms require no sticking at their edges, being far neater than those which do. They have the semblance of solidity, and as each face involves at least two thicknesses, their stability is secured. They allow of the measurement of their edges with a *goniometer*. Being so easily made, an opportunity is afforded of enclosing a series of gradually enlarging hollow models (see Figs. 97, 101, 104) over each other upon a central nucleus (like nested boxes)—the process imitates the growth of a natural crystal, and the compound nucleated model indicates by the use of needles the direction of its *cleavage*.

Finally, the plaiting of a cube suggests a possible manner in which the crystal particles may start originally from a common root, and travel in certain definite directions until the material by which they are fed becoming exhausted, their growth ceases, and their form is completed.

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A SYSTEM

FOR THE

CONSTRUCTION OF CRYSTAL MODELS

ON THE TYPE OF AN ORDINARY PLAIT.

It is a property inherent in the ordinary plait that its constituent parts shall cohere compactly without adventitious aid. This involves definite arrangement; and if this arrangement is studiously followed in the construction of models, their faces will in like manner become coherent, and, when plaited, will assume a solid form, and maintain it without extraneous assistance. Hence, to make a model by this method, it is essential that the natural collocation of the parts in an ordinary plait shall be defined in numerical order, and that this order, when once obtained, shall be implicitly followed in the making of every crystal form, however much the shapes of its faces may vary.

An ordinary plait of three or four flexible narrow strips is so easily put together that the process would appear scarcely more than intuitive. On making an outline of the common plait, Fig. 1, we notice that the strips intersect or cross one another in a manner so definite, that it may be easily specified in numbers, each number, from below upwards, indicating the place of intersection. That part of the one strip which overlaps is denoted by an ordinary numeral; that which is overlapped, or lies underneath, by the same numeral, barred thus: 1 and $\bar{1}$. On now unfolding the form we find the projection, Fig. 2, with its numbers so disposed, that, were we previously unable to make this ordinary plait, the projection alone would enable us to do so. It will be noticed, however, that the figure thus obtained is capable of extension in one direction only: it may be

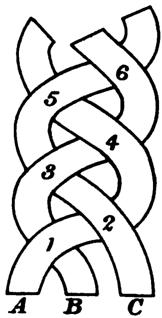
elongated, but is devoid of solidity. To obtain a model having the form of a *solid*, we take three strips composed of square faces, Fig. 3, upon which we transcribe the numbers exactly as they are disposed in Fig. 2; and finally, instead of allowing the three strips to lie parallel on commencing the plaiting, we place the strip marked C at right angles to the other two strips marked A and B. The projection, Fig. 4, will now make up into the *cube*, Fig. 5, shown in its projected state, Fig. 6.*

The numerical order in which the faces combine to form a plaited model of the *cube* is thus secured, and this order is retained as the type on which crystal models may be constructed.

The uses to which the *cube* is applied are so multifarious, that the ability to construct a model of it by a process at once so easy, certain, and rapid, must needs be a desideratum. Amongst the natural crystal forms a very considerable number are geometrically allied to the cube, and the common type on which their configuration is based is so absolutely identical, that the primitive forms belonging to the six axial systems in crystallography may, one and all, be constructed upon it. Take, for instance, the parallelopipeds known as the six-sided *prisms*; the *rhombohedrons*, acute and obtuse; the *octahedrons*, from the regular to the doubly oblique; the elegant *scalenohedron* with its allied *calcite*. By strictly adhering to the numerical order in this cubic projection a series of *sub-types* can be produced, resulting in modifications which exemplify the forms of natural crystals; witness the *typical tetrahedron*, Fig. 24, under which head are comprised those irregular tetrahedral solids named

* The best material for making these models has been found to consist of *glazed cambric* and *white demy paper*, pasted together into sheets, and well pressed, so as to be entirely clear of air-bubbles. Cardboard is useless, breaks at the bends, and drops to pieces. On making a projection of the pattern on a flat surface, a face of the model is cut out in cardboard: a square for the cube, for instance, round which the outline is traced with a pencil; for if drawn with ruler and compasses, the faces are brought too close to plait properly. It imparts finish to a form by cutting separate pieces from a sheet of stone-coloured cardboard, exactly equal in number and shape to the faces of the model itself. When pasted with care, the form becomes scarcely distinguishable from that of a solid. Sample specimens may be procured, however, of Mr. Henson, Mineralogist, 227, Strand, London, W.C.

Fig. 1.



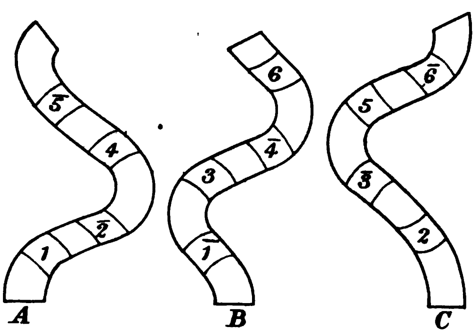


Fig. 2.

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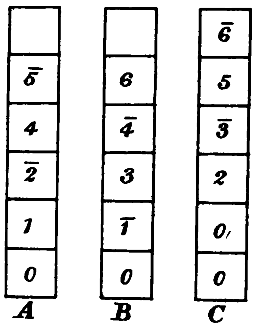
Fig. 3.



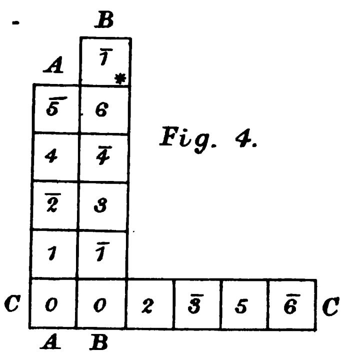


Fig. 4.

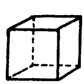


Fig. 5.

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CUBE

ADJUSTMENT OF ITS PLANES DERIVED FROM ORDINARY PLAIT.

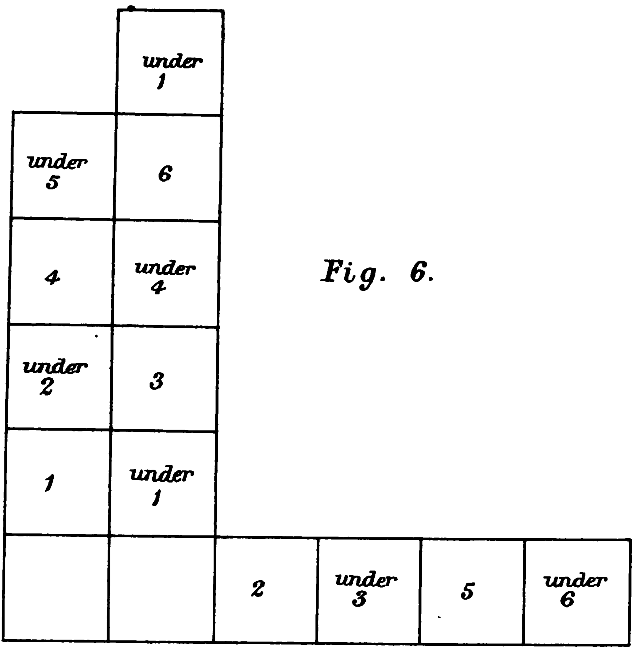

Fig. 6.

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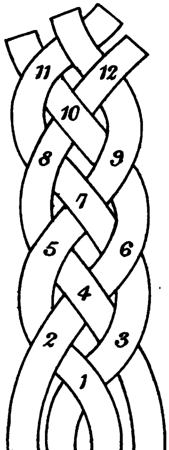
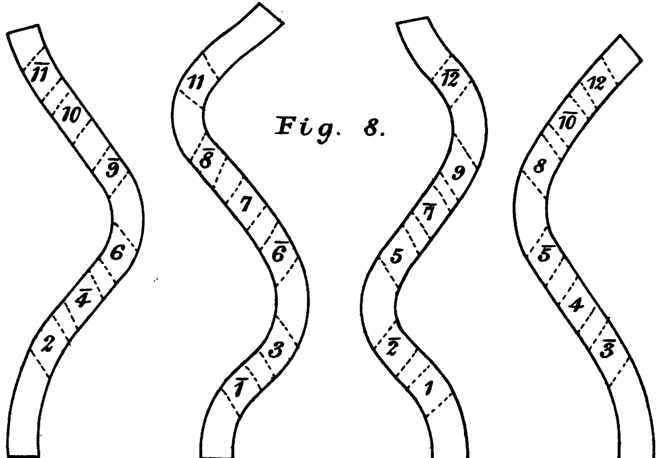
Fig. 7. Plait of 4 strips.

Fig. 8 the same unplaited. The spaces overlapped in each strip are distinguished by barred numbers thus $\overline{1}$ which means under 1. &c.



A B C D

Fig. 7.



A B C D

Fig. 8.

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sphenoids, themselves being *hemihedral* forms of their respective octahedrons.

Owing to the remaining forms being contained under a greater number of faces, they cannot, of course, be made by using a cube composed of three fillets only. An additional fillet is therefore added, by the aid of which we are enabled to construct a *second* cube more composite in its nature, but still a cube, the projections of which supply us with all the remaining solids. The cubic type thus maintains its supremacy, while the unity of the system is preserved.

To construct a *cube* with a plait of *four* fillets, let A B C D, Fig. 7, be four strips intertwined in the usual way to form a plait, and let them be numbered in the order of their intersections, from below upwards, as in the diagram. Then, as each intersection involves two faces, the one overlapping the other, let the upper one be denoted by an ordinary numeral, say 3, and the lower one with a *barred* numeral, say $\bar{3}$, as in Fig. 8.

Fig. 9.—The strips are drawn in a rectilinear direction. They are composed of square faces, which are numbered like those in Fig. 7. The base planes are indicated by small circles (ȯ); those which give security to the whole are defined by an asterisk (*).

In Fig. 10, the four series are arranged in the true order for plaiting, in which the two innermost strips, B and C, are placed perpendicular; while A and D are projected horizontally. A diagonal in dotted lines across each square completes the figure, and each square is creased along the diagonal.

The process of plaiting commences by bringing the face numbered 1 in C over that marked $\bar{1}$ in B; next, the face numbered 2 in A is carried over that marked $\bar{2}$ in C, and so on until the planes are exhausted.

Fig. 11 shows in isometric perspective a model of the resulting solid. It is a cube, each face of which, instead of being one entire piece, is composed of four isosceles triangles of 90°, which appear set like a mosaic. It has been constructed in this way for the purpose of showing many of the highly interesting forms which are recognised in crystallography as modifications on the faces of a cube. These modifications are

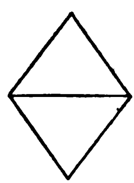
produced by varying the angular value of the isosceles faces. When they are equal to 90°, the form is a cube. When less than 90°, say 83°, a pyramid of four sides is raised on each face as in some varieties of *quartz;* while, if still further reduced, say to 70° 31′ 44″, the resulting model is that of the well-known and beautiful form known as the *rhombic dodecahedron*, of which the garnet is a familiar example.

The Rhombic Dodecahedron is bounded by twelve similar and equal rhombs, the plane angles of which are equal to 109° 28′ 16″ and 70° 31′ 44″.

The faces incline to each other at the edges at an angle of 120°. It is geometrically allied to the cube, for if the twelve edges of the cube are replaced by tangent planes, and these are extended until they mutually intersect, the rhombic dodecahedron will be formed.

To find the *plane angles of the rhombic face*:—These are discovered by the formula $L \dfrac{1}{2 \sin \frac{1}{2} A} = \cos \frac{1}{2} a$,

$$\text{where } \cos \tfrac{1}{2} a = 54° \, 44' \, 8''$$
$$\text{and } a = 109° \, 28' \, 16'' \, *$$



Rhomb and Short Diagonal.—We now revert to our typical projection, Fig. 10, with its *zigzag dotted diagonals*, and trace on a sheet of paper outlines of the rhombic face in the same numerical order, making its *short diagonal* correspond in direc-

* A mode of finding this plane, which is useful for practical purposes, is to make the short diagonal of the rhomb equal to the side of a square, and the long diagonal of the rhomb equal to a diagonal of the square. A more elegant mode is as follows:—Let the short diagonal of the rhomb be taken as 1, then the long diagonal will be equal to $\sqrt{2} = 1 \cdot 414$, and any side of the rhomb will be equal to

$$\frac{\sqrt{3}}{2} = \frac{1 \cdot 732}{2} = 0 \cdot 866.$$

The Curved Strips in Fig. 8 are here set out in their true acetilineal order for final adjustment, as in Fig. 10.

Fig. 9.

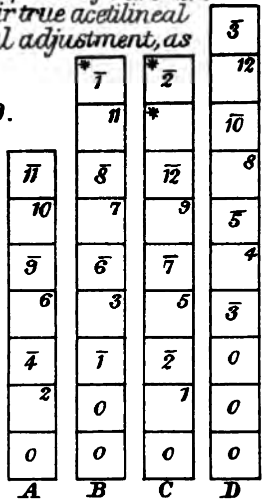
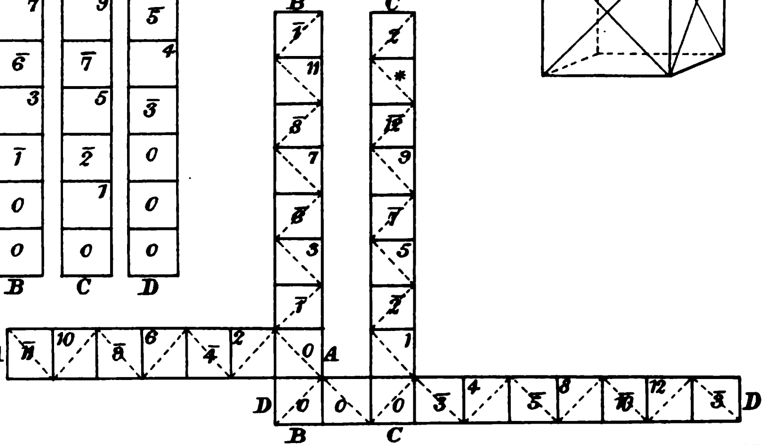


Fig. 10.

TYPICAL CUBE ADJUSTMENT.



TYPICAL CUBE.

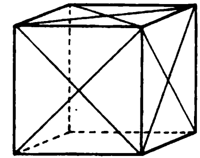


Fig. 11.

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RHOMBIC DODECAHEDRON.

109° 28' 16"
70° 31' 44"

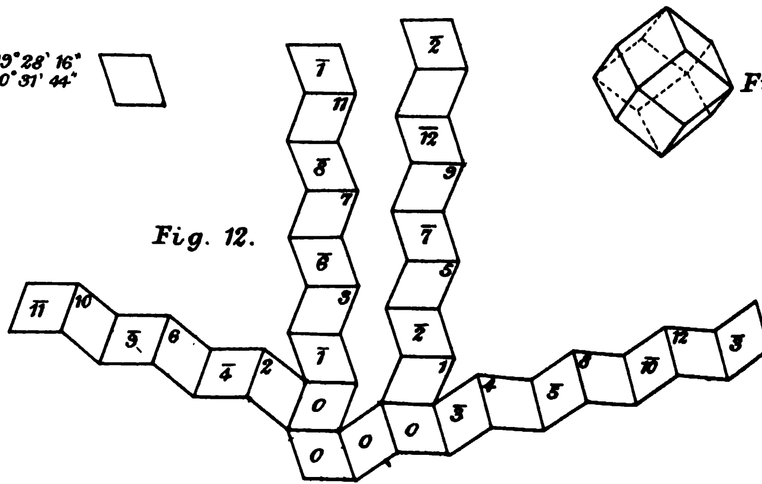

Fig. 12.

Fig. 13.

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REGULAR OCTAHEDRON AND CUBE.

Fig. 14.

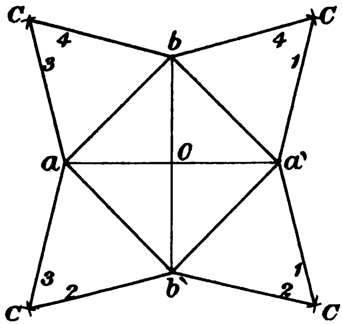
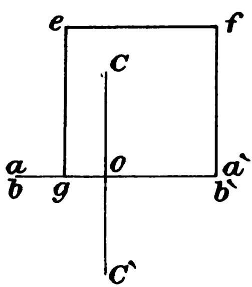


Fig. 15.



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tion with that of the *zigzag* lines. The faces are now numbered in the same way, and the projection, Fig. 12, will plait into an elegant and firm model of the *rhombic dodecahedron*. (Fig. 13.)

The First System.

Each system is defined in accordance with the relative *length* of its *axes*, and the angle of their intersections. In the first system the angles are *equal* in length, and cut in the centre at *right* angles. (For cube, see Fig. 6.)

Regular Octahedron.—A solid bounded by eight faces, which are equilateral triangles; inclination of faces at their edges equal to 109° 28′ 16″; edges, twelve; solid angles, six.*

It is proposed to elicit from the axes—

1. The planes or faces of the model;
2. The method of locating their sides;

and then from the cube itself—

3. The mode of adjusting the faces to form a plaited model of the octahedron.

To find a face of the octahedron, although this is known from the above definition, it is proposed to obtain it direct from the axes, in order that the same method may be employed in the case of other forms which are more complicated, and where the faces are not known. Let the straight lines *a*—*a′*, *b*—*b′*, Fig. 14, be called the first and second axes of the system, and let *c*—*c′*, Fig. 15, be the third axis. For convenience' sake, let each of them measure 2·2 inches.

Assuming that every octahedron is composed of two four-sided pyramids, having one common base, join *a b a′ b′*, Fig. 14, by straight lines: the common base is equal to *a b a′ b′*, Fig. 14.

To find the *triangular faces from the axes*:—Let *c o*, Fig. 15, be equal to half the third axis, and let the lines *a a′*, *b b′* represent the first and second axes, and let it cut *c o* at right angles.

With radius equal to *a c*, Fig. 15, set off the arc *a c*, Fig. 14; and with radius *b c*, Fig. 15, set off the arc *b c*, Fig. 14. The

* Listing explains and generalises the so-called *theorem of Euler about polyhedra*, viz. that if S be the number of solid angles of a polyhedron, F the number of its faces, and E the number of its edges, then $S + F = E + 2$. See Prof. Tait on 'Listing's Topologie,' p. 46.

two arcs shall cut in *c*, and the *equilateral triangle a b c* is the *face required.*

The three remaining faces are set off upon their common base in the same way by reference to the letters.

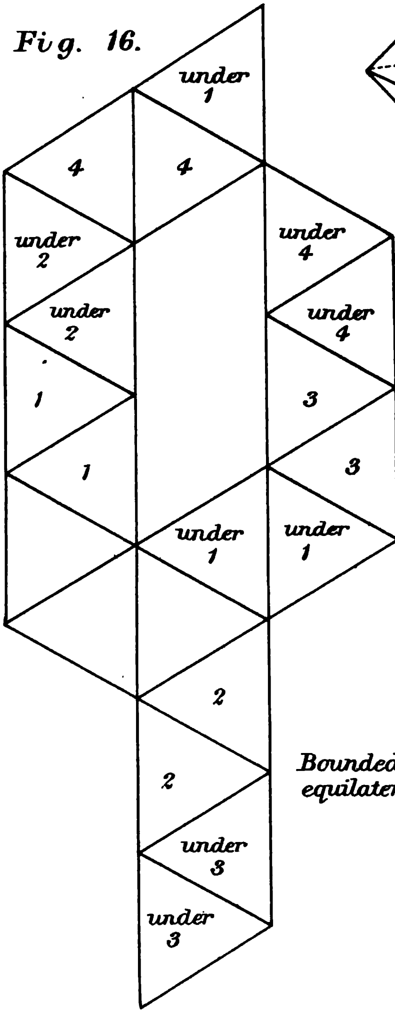
Here, then, we have four faces projected upon their common base, and forming, when brought together at their sides, one of the pyramids. Each triangle is now distinguished by using numerals, which are so disposed that any two sides which are marked with the same number will correspond in length, and form an edge when united. By this arrangement there is obtained not only the actual magnitudes of the sides of the faces of the octahedron, but also there is given a name to the sides of every two adjoining faces which are to form an edge by their union. This method provides the limit to what *can* and what *cannot* be accomplished by the process of plaiting: it *can*, and does, furnish us with the true adjustment of the faces themselves in making a model; but it *cannot* locate the sides of those faces. This requires the use of arbitrary numbers, each side being represented by its own numbers; and when this is effected in the case of the regular octahedron, it answers for all the rest.

On contrasting this solid with the *cube*, we notice that two forms totally distinct from one another—the one bounded by *six* faces, the other by *eight*—are adjusted in precisely the same numerical order. This was solved by taking an *obtuse rhombohedron,** the plane angles of the faces of which were equal to 60° and 120°. When creased in their short diagonals, these faces became converted into twelve equilateral triangles, exceeding by four, be it observed, the number actually required to make the octahedron. It was found, however, that this extra number exactly corresponded with that which was required for the foundation and finishing planes of the model. From this peculiarity in its construction it results that *each pair of triangles must be counted as one plane* throughout. Thus constructed, the manipulation will be found to be exactly that of

* Not the solid itself which with plane angles of this value is an impossible form, but the planes projected as if for any other obtuse rhombohedron, for the projection is the same in all.

REGULAR OCTAHEDRON.

Fig. 16.



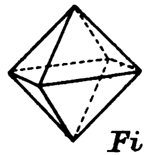


Fig. 17.

Bounded by 8 similar equilateral triangles.

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TYPICAL OCTAHEDRON.

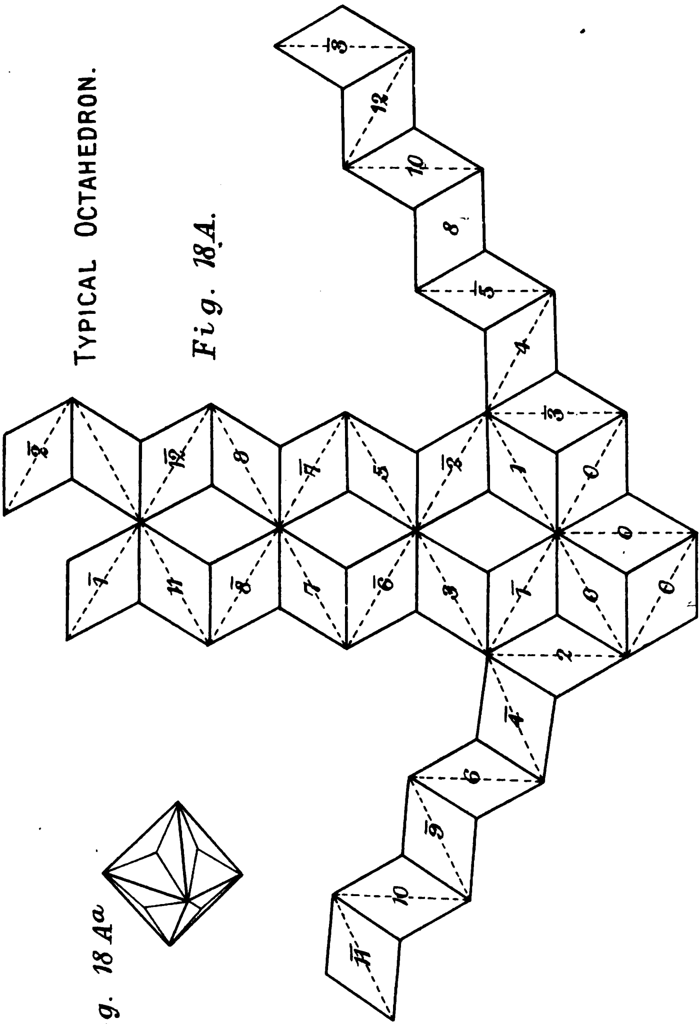

Fig. 18 A.

Fig. 18 Aa

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the cube, and every octahedron from the *regular* to the *doubly oblique* may be made up with the same facility.

To show that the *quasi rhombohedron* from which those speculations and results have been obtained, has no actual existence, see Figs. 78 and 79.

Mode of Using the Key.

On the following page a key is given for making all the octahedrons, and on the opposite side the faces or planes under which they are contained. To use this key, a single glance will suffice to show that each face (which is supposed to be cut in cardboard), when traced round on a piece of cartridge-paper exactly in the order prescribed by the key, will make in the aggregate the projected model of its own octahedron. The numbers on the card pattern are sometimes made on one side; if on both, the card is reversed, and the required numbers are then appended as shown in the triangles of dotted lines.

It will be noticed in the key that certain of the faces are *shaded;* this is done to indicate that in tracing the outlines of such faces the *card pattern* is to be *reversed;* for on carefully examining the two opposite pyramids set on a common base of any octahedron, it will be found that while the faces of the two pyramids are all exactly alike, those of the one pyramid are always the reverse of the faces of the other pyramid.

Typical Octahedron.—So called, because by its use pyramids of a given height may be raised on all the faces of the *regular octahedron.* In its present form the three isosceles triangles composing a face are equal to 120°; these when meeting lie in one plane, and the model is that of a regular octahedron, with each face composed of three pieces instead of one. On making the isosceles angles equal to 118° 57′ 55″, a low pyramid is obtained, and the form becomes that of the *octahedral fluor haloide*, and is called an *octahedral trigonal isositetrahedron*—that is, a crystal of twenty-four isosceles triangles, having an octahedral aspect. If the isosceles angles are diminished to 109° 28′ 16″, the well-known *rhombic dodecahedron* is the result.

The projection, Fig. 18A, consists of thirty-two similar and equal rhombs of 60° and 120°, adjusted as in the figure. Each

rhomb is creased in the direction of the dotted lines, and is plaited by bringing the face numbered 1 over the opposite face numbered $\overline{1}$, and so on in numerical order until the model figure A *a* is obtained.

Tetrahedron.—The tetrahedron, a regular solid of geometry, is contained under four equilateral triangles, and therefore all its plane angles are equal to 60°. The faces incline to each other at the edges at an angle of 70° 31′ 44″.

The projection for making the plaited model of this solid is shown in the subjoined Fig. 19:—

The tetrahedron is a half form (hemihedral), that is, has half the number of faces of the regular octahedron, the alternate faces of which when enlarged to infinity cut one another, and produce a model of four instead of eight faces.

Sphenoids.—A sphenoid (from σφηv, ηvὸς, *cuneus*, a wedge) is an irregular tetrahedron; it bears the same relation to *its allied* octahedron, of which it is the hemihedral form, as the tetrahedron does to the *regular* octahedron. The sphenoids resemble the tetrahedron, in having the same number of triangular faces; but the triangles are never equilateral. They are projected for modelling like those of the tetrahedron.

Tetragonal Sphenoid is bounded by four similar and equal isosceles triangles, and is derived from the *right square octahedron.* (Fig. 20.)

Right Rhombic Sphenoid.—Bounded by eight similar and equal scalene triangles—derived from *right rhombic octahedron.* (Fig. 21.)

Oblique Sphenoid.—Bounded by scalene triangles of two kinds —derived from *oblique rhombic octahedron.* (Fig. 22.)

Doubly Oblique Sphenoid.—Bounded by scalene triangles of four kinds—derived from *doubly oblique rhombic octahedron.* (Fig. 23.)

Tetrahedron (Typical).—For crystal purposes this form is best made by resolving each of its triangular faces into three *isosceles* triangles of 120°, which when plaited meet in the centre, and form one plane. When the isosceles angles are less than 120°, they become elevated from the centre, and rise in the form of a three-sided pyramid on each face. In *tetrahedral copper-glance*, for instance, the angles are equal to 117° 2′ 8″, and

KEY TO THE ADJUSTMENT OF THE FACES OF ALL THE OCTAHEDRONS.

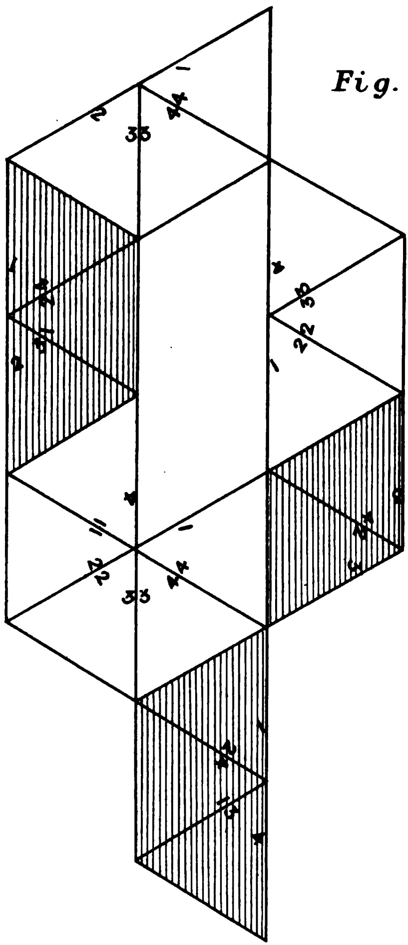

Fig. 18.

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FACES OF ALL THE OCTAHEDRONS OF AXIAL SYSTEMS. FOR KEY.

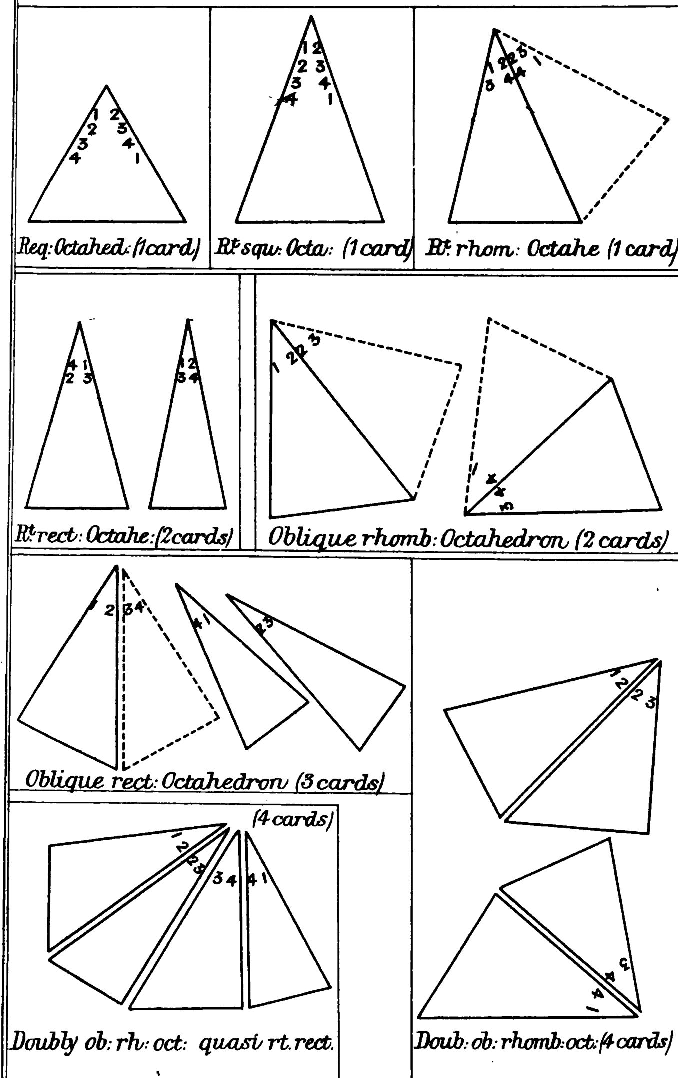

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Fig. 19.

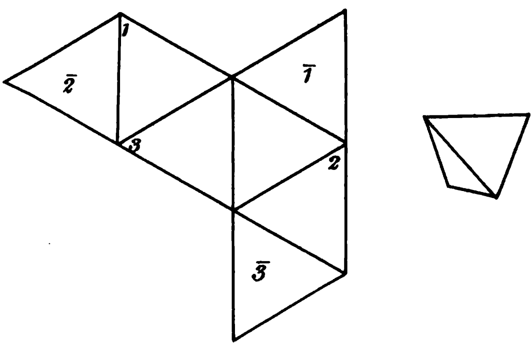

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Fig. 20.

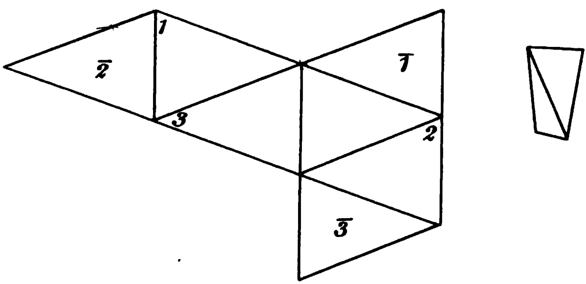

Fig. 21.

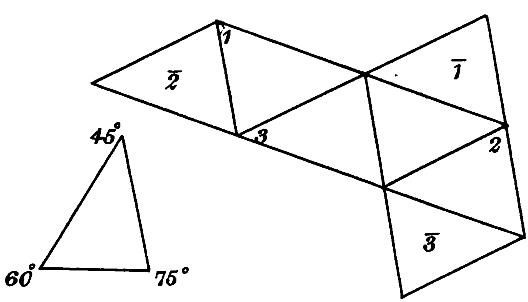

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Fig. 22.

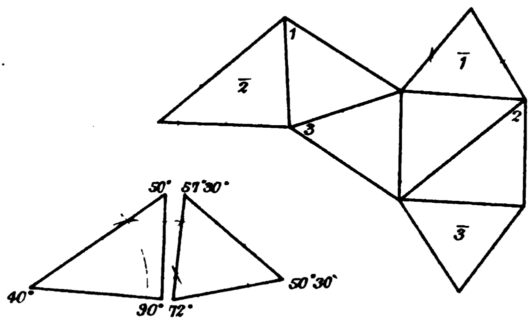
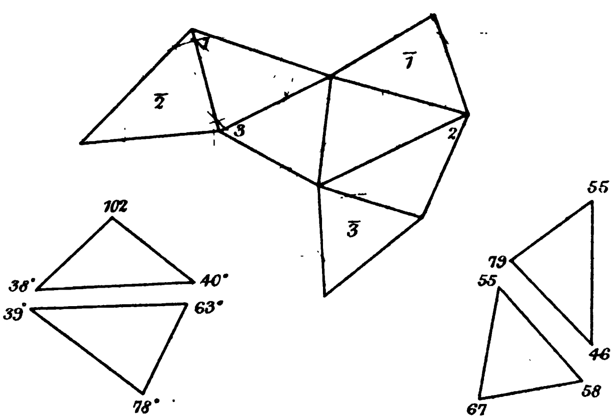


Fig. 23.



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RIGHT SQUARE OCTAHEDRON.

Fig. 29.

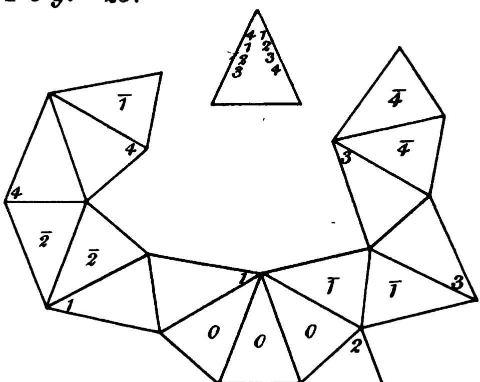
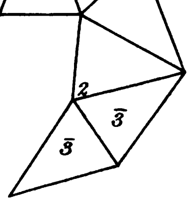

Fig. 30.

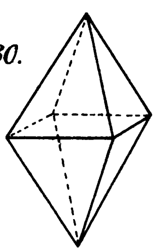

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Fig. 26.

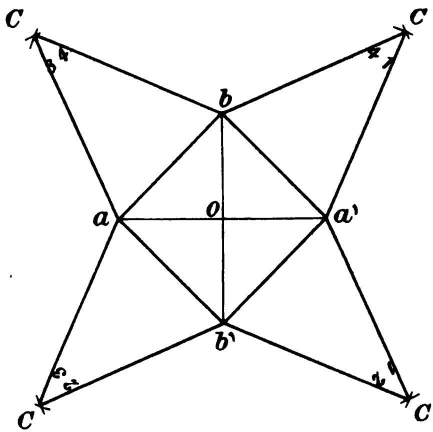
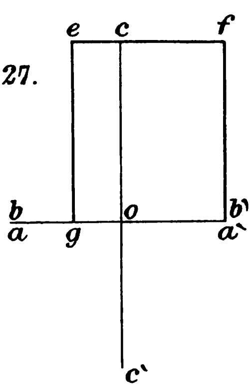


Fig. 27.



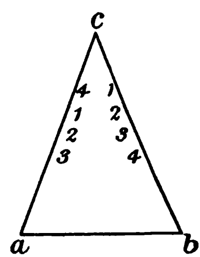


Fig. 28.

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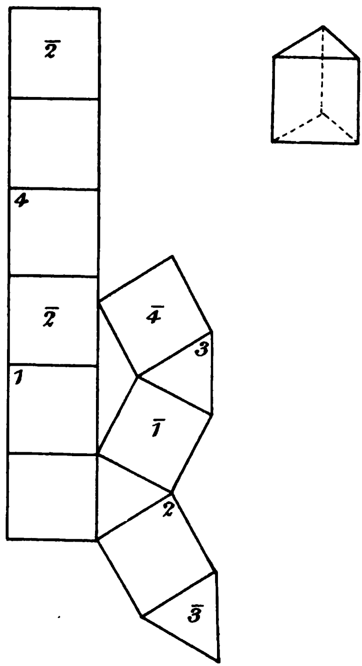
Fig. 25.



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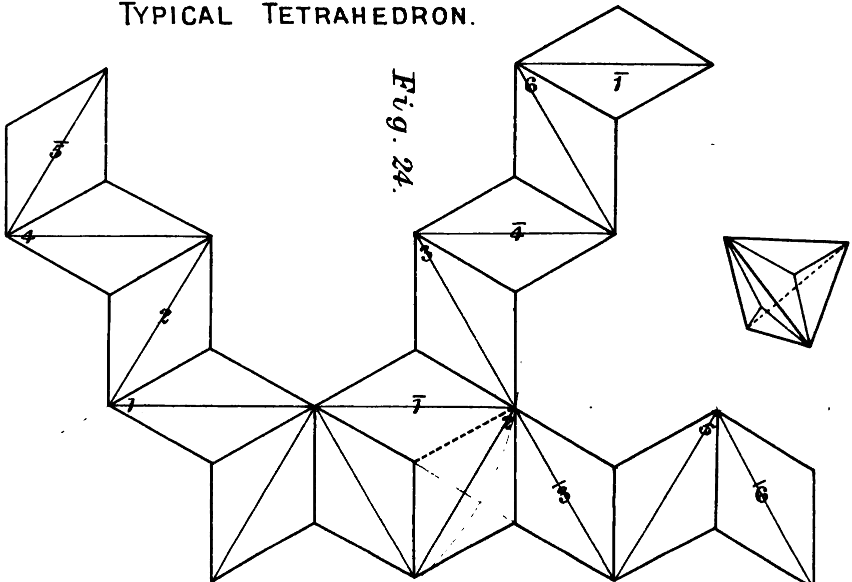
TYPICAL TETRAHEDRON.

Fig. 24.



the pyramid is low. In *dodecahedral garnet-blende* the isosceles angles are reduced to 112° 53′ 7″, the pyramids becoming raised in proportion. The limit to these modifications consists in making the isosceles angles equal to 90°; the resulting form is a *cube*. By using this method of making the tetrahedron, the relation between it and the cube, and the transition from the one form to the other, are well displayed. It is essentially a typical model representing something which is capable of being evolved on one and the same type, by the mere alteration of the plane angles of its isosceles faces. (Fig. 24.)

Triangular Prism is contained under five planes—three lateral, which are squares or rectangles, and two terminal, which are equilateral triangles. From the fact of its being used by Newton to decompose white light into its seven primitive colours, this form is familiar to every one. (Fig. 25.)

To make the model, the planes are projected in the same order as in the cube.

Square Prismatic System

has three axes, all at right angles, one longer or shorter than the other two. (In our examples the third axis is taken longer than the other two.)

Forms :—*Right Square-based Octahedron.*
Right Square Prism.

Right Square Octahedron.—To find the *base* (Fig. 26):—Draw *a*—*a′* and *b*—*b′* (the first and second axes), equal to 2·2 inches. Because they are equal and rectangular, the square formed by joining their extremities by four straight sides is the *base of the octahedron*, that is, the base common to the two isosceles pyramids composing the solid.

To find the *triangular face* (Fig. 27):—Draw *c*—*c′* (the third axis) equal to 3·3 inches, and let it be bisected in *o*, and let *a*—*a′* (the first axis) be perpendicular to *c o*. With radius *a c* place one foot of compasses in *a*, Fig. 26, and describe the arc *c*; with same radius describe the arc *b c*. The triangle *a b c* is a face of the octahedron. Because the faces are all equal, the three remaining triangles are found in the same way by using the

*

same radius. To distinguish the sides of the faces the numerals are now added; and these are repeated on the cardboard pattern of the face, Fig. 30. This pattern being the same for all the outlines, would imply indifference as to position; but reference to the key, Fig. 18, shows that the plan of each side of every plane is fixed and definite.

Right Square Prism (Fig. 32).—Bounded by six planes, four of which are rectangular, and two square.

To find the *square planes* from the axes :—Draw the first and second axes *a—a'* and *b—b'*, Fig. 26, intersecting in *o* at right angles. Join the ends of the axes by straight lines; then *a b a' b'* is a *square plane* of the prism.

To find a *lateral plane* of the prism by measurement from the axes :—Draw *c o*, half the third axis, and *a—a'*, the first axis, at right angles to one another. With compasses take *a b*, a side of the square base, Fig. 26, and measure this distance along the line *a' g*, Fig. 27. The parallelogram *a' g e f* is the *lateral plane.*

To make the model, these two faces are adjusted like those of the cube, as in the following Fig. 31; Fig. 33, terminal plane; Fig. 34, lateral plane.

Rhombic System

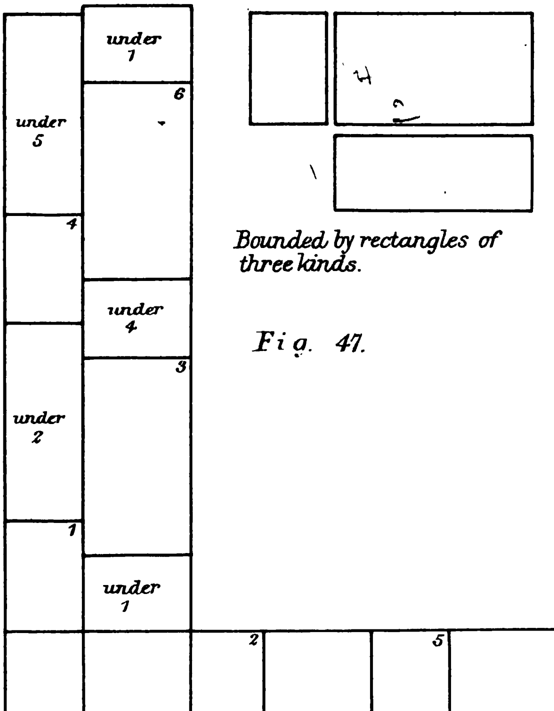
has three axes of unequal length, at right angles to each other.

Forms :—*Right Rhombic-based Octahedron.*
Right Rhombic Prism.
Right Rectangular-based Octahedron.
Right Rectangular Prism.

Right Rhombic Octahedron.—To find the *base* :—Let the first and second axes *a—a'* and *b—b'*, Fig. 33, cut at right angles in *o*. Join the extremities by straight lines; the rhomb *a b a' b'* is the *base* of the octahedron.

To find a *triangular face* :—Draw the half of the third axis, *c o*, Fig. 36, equal to 1·8 inch, and the second axis *b—b'*, equal to 2·2 inches. Make the first axis *a—a'* equal to 1·6 inch, and let it be measured along the second axis *b—b'*.

RIGHT RECTANGULAR PRISM DERIVED FROM RIGHT RHOMBIC PR.



Bounded by rectangles of three kinds.

Fig. 47.

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RIGHT RECTANGULAR OCTAHEDRON DERIVED FROM RIGHT RHOMBIC OCTAHEDRON.

Fig. 45.

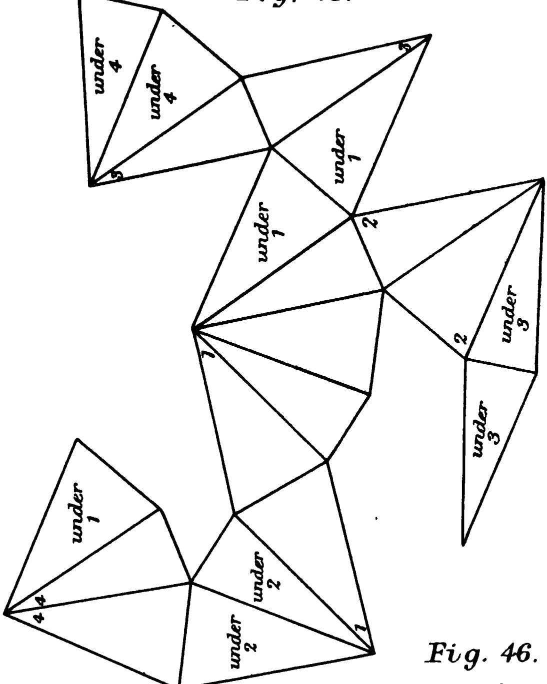
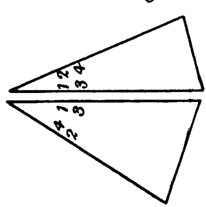


Fig. 46.

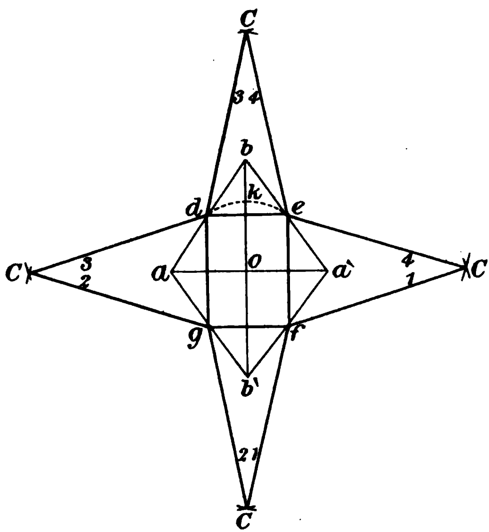


Bounded by isosceles triangles of two kinds.

E & F. N. Spon, London & New York.

RIGHT RECTANGULAR OCTAHEDRON AND PRISM.

Fig. 43.



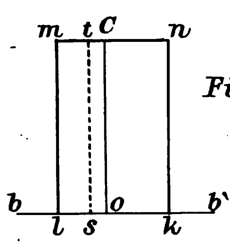


Fig. 44.

E & F.N. Spon, London & New York.

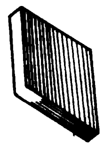
RIGHT RHOMBIC PRISM

THIRD AXIS SHORTER THAN THE OTHER TWO.

Micros: Crystal Uric acid.

Fig. 40.

Fig. 42.



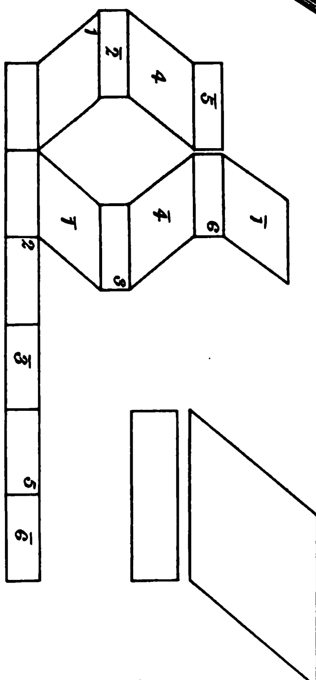
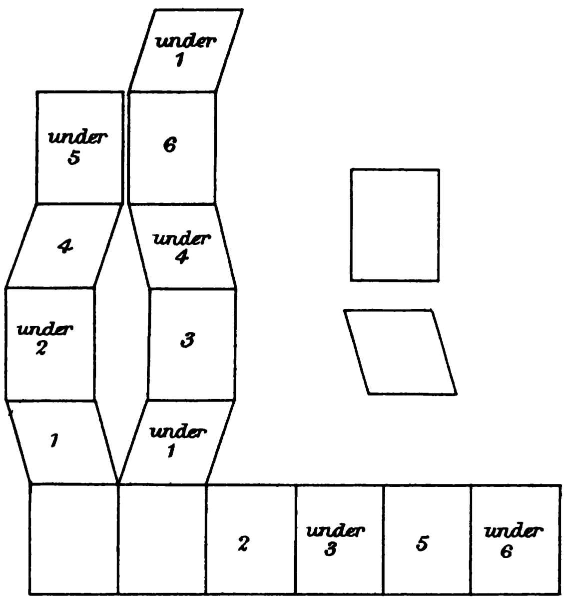


Fig. 41.

E & F.N. Spon, London & New York.

RIGHT RHOMBIC PRISM.

Fig. 39.



E & F. N. Spon, London & New York.

RIGHT RHOMBIC OCTAHEDRON.

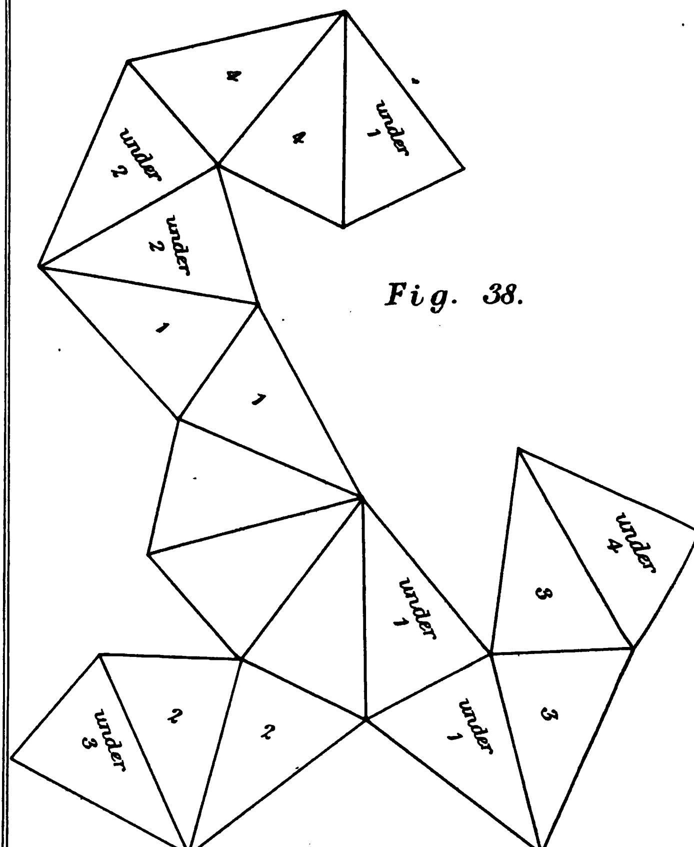


Fig. 38.

E & F.N. Spon, London & New York.

RIGHT RHOMBIC OCTAHEDRON AND PRISM.

Fig. 35.

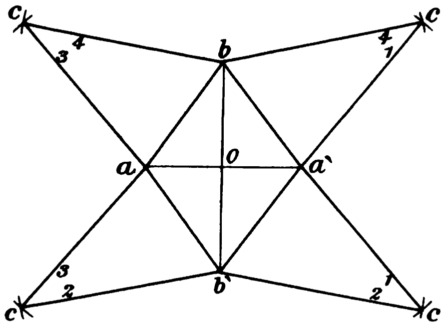


Fig. 37.

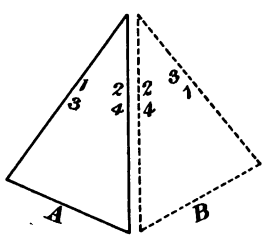
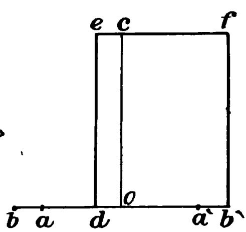


Fig. 36.



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RIGHT SQUARE PRISM.

Fig. 31.

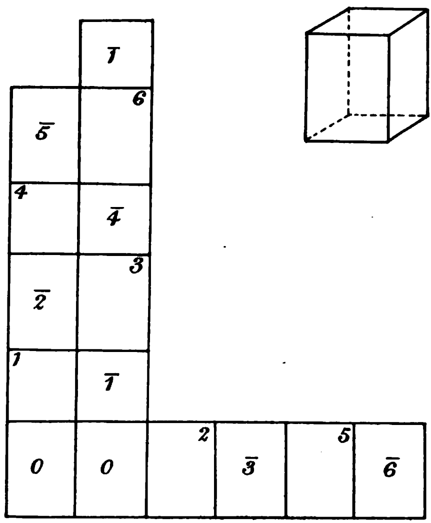
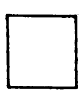


Fig. 32.

Fig. 33.



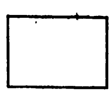


Fig. 34.

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With compasses and with radius *c a*, Fig. 36, describe the arc *a c*, Fig. 35, and with radius *b c*, Fig. 36, describe the arc *b c*, Fig. 35; the two arcs shall cut in *c*, and the *scalene* triangle *a b c* is a face of the octahedron. Similarly, let the remaining triangles be set off from the sides of the rhombic base by reference to the letters in Fig. 36, and let each triangle be supplied with numerals exactly in the same order as in Fig. 26.

To adjust the faces by the key, Fig. 18, so as to obtain the projection of the model:—Cut out of cardboard the triangle *c a' b'*, Fig. 35. This constitutes the pattern round which the tracings are made of every triangle in the model.

On the *obverse* face of the pattern write the numbers $\left\{\begin{matrix}1, 2\\3, 4\end{matrix}\right.$; and on the *reverse* face, shown by the dotted lines, the numbers $\left\{\begin{matrix}2, 3\\4, 1\end{matrix}\right\}$. (Fig. 37.)

Now let outlines of the pattern be traced on a sheet of cartridge-paper, so that the numbers on the pattern and on the key shall correspond, being careful that *where the planes are shaded* the *pattern is reversed* before making its outlines.

Finally, having obtained the projection, Fig. 38, let the order in which the faces are to be plaited into the model be indicated by the numbers as shown in Fig. 16.

To find the six planes of the *right rhombic prism*:—These consist of two terminal faces which are *rhombs*, and four lateral planes which are *rectangles*.

To find the *rhombic or terminal faces*:—Let the first and second axes *a—a'* and *b—b'* intersect in *o*, Fig. 35, at right angles. Join their extremities by straight lines; the rhomb thus made is the *terminal face* required.

To find the *lateral planes* of the right rhombic prism:—On the line *b' b*, Fig. 36, measure off *b' d* equal to *a b*, Fig. 35. Make *d e*, Fig. 36, equal to *c o*, and describe the parallelogram *b' d e f*, which is the *required lateral plane.*

To adjust the planes on a plane surface for the purpose of plaiting them into the model, see Fig. 39.

Right Rectangular Octahedron—derived from the right rhombic octahedron—bounded by eight isosceles triangles of two kinds.

To find the *base*:—Bisect the sides of the rhomb *a b a' b'*, Fig. 43. Join the bisecting points by straight lines; the rectangle *d e f g* is the *base* of the octahedron.

To find the *faces*:—With radius *o d*, Fig. 43, draw the arc (dotted lines) *d e*, it shall cut *b b'* (the second axis) in K. Measure *o* K along *b b'*, Fig. 44; then *c* K is equal to any side of an isosceles face, and the triangles *c d e* and *c d g* are the two faces of the octahedron.

Right Rectangular Prism is contained under six faces, which are rectangles—two terminal and four lateral.

To find the two *terminal planes*:—These are equal to the base of the octahedron *d e f g*.

To find the two *broad lateral planes*:—Along the line *b b'*, Fig. 44, measure K *l* equal to *d g*, Fig. 43, and describe the parallelogram K *l m n*, which is equal to the required plane.

To find the *narrow lateral planes*:—On the line *b b'*, Fig. 44, measure K *s* equal to *d e*, Fig. 43. The parallelogram K *s t n* is equal to the lateral plane required.

Oblique Prismatic System.

Three axes, all unequal in length: two, *a—a'* and *b—b'*, at right angles; the third, *c—c'*, oblique to one and perpendicular to the other.

Forms:—*Oblique Rhombic-based Octahedron.*
Oblique Rhombic Prism.
Oblique Rectangular-based Octahedron.
Oblique Rectangular Prism.

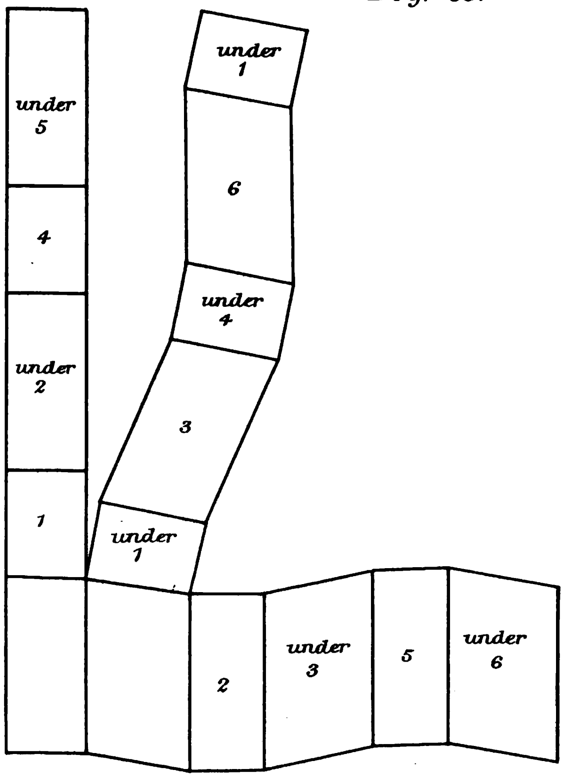
Oblique Rhombic-based Octahedron.—Contained under eight *scalene* triangles of two kinds.

To find the *base*:—Draw the first axis (*a—a'*) equal to 1·6 inch, and the second axis (*b—b'*) equal to 2·2 inches, at right angles to one another. Let the extremities be joined by straight lines. The rhomb *a b a' b'* is the *base*.

To find the two *triangular faces* (Fig. 49):—Draw *c o* (half the third axis) equal to 1·8 inch, *a—a'* (first axis) equal to 1·6 inch, at right angles to one another. Let *b—b'* (the second axis) cut *c o* in *o* obliquely, so that *c o b'* shall be equal to 120°.

OBLIQUE RECTANGULAR PRISM.

Fig. 63.



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Oblique rectangular Octahedron.

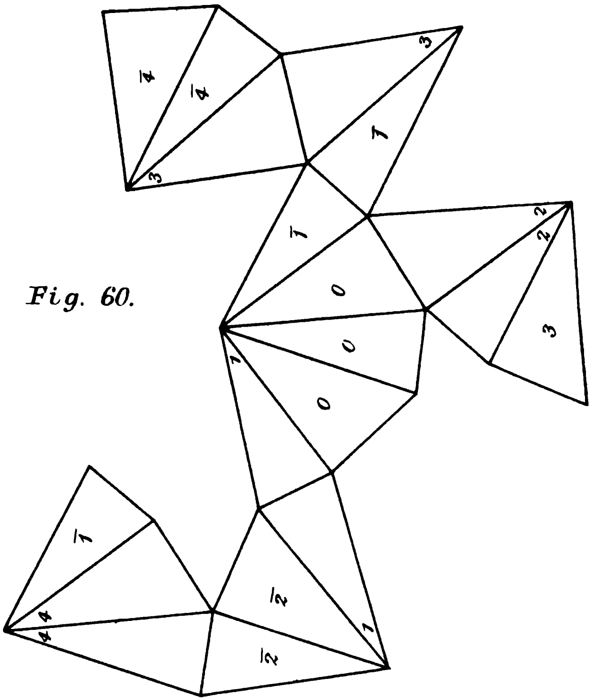


Fig. 60.

Fig. 61.

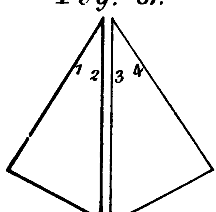
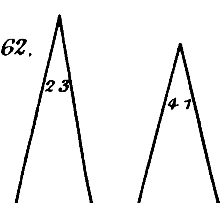


Fig. 62.



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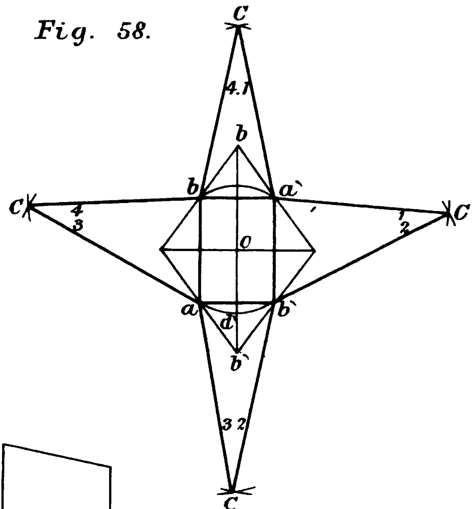
OBLIQUE RECTANGULAR OCTAHEDRON AND PRISM.

Fig. 58.



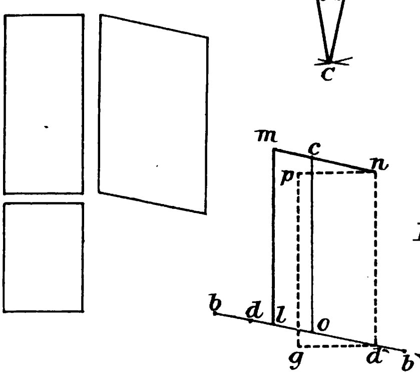


Fig. 59.

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OBLIQUE RHOMBIC OCTAHEDRON. (cob' = 120°)

Fig. 50.

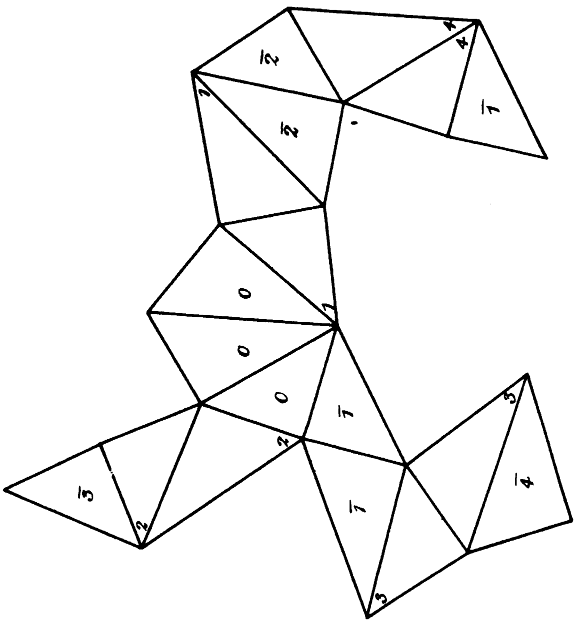


Fig. 51

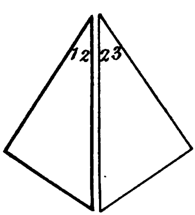
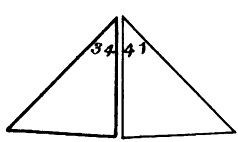


Fig. 52.



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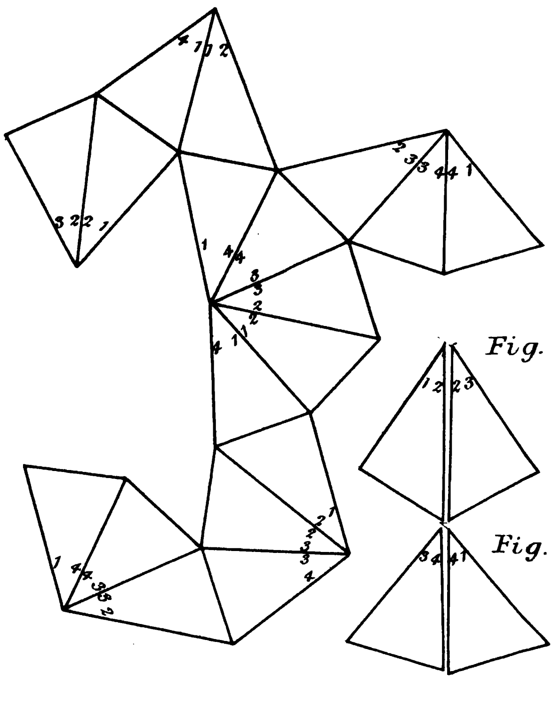
OBLIQUE RHOMBIC OCTAHEDRON. (cob` = 100°)

Fig. 53.

Fig. 54.

Fig. 55.



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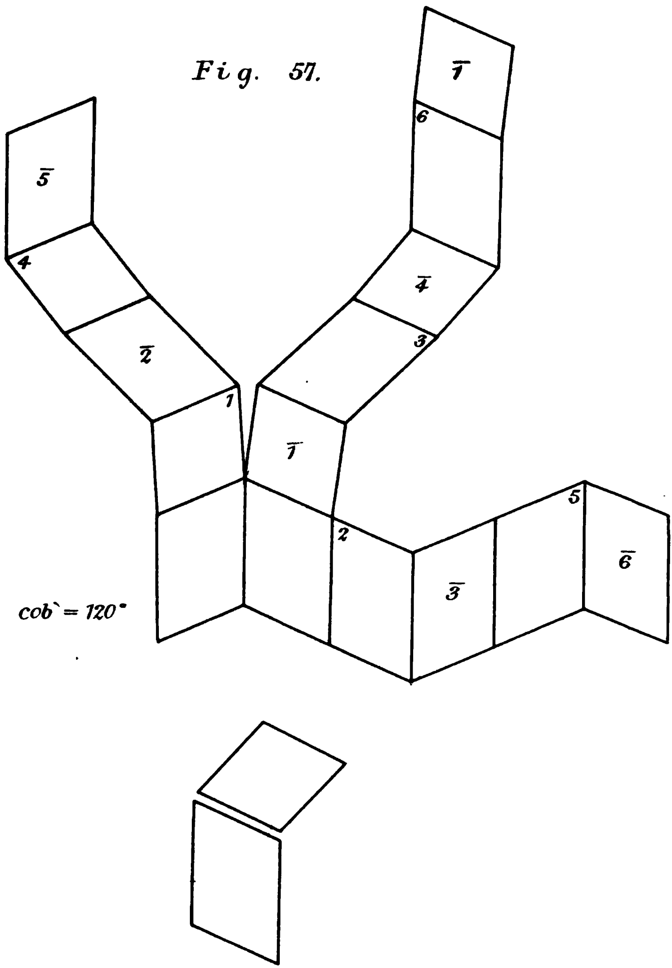
OBLIQUE RHOMBIC PRISM (VAR. 2)
(OBLIQUITY IN SHORT DIAG: OF TERMINAL PLANE)

Fig. 57.



$cob' = 120°$

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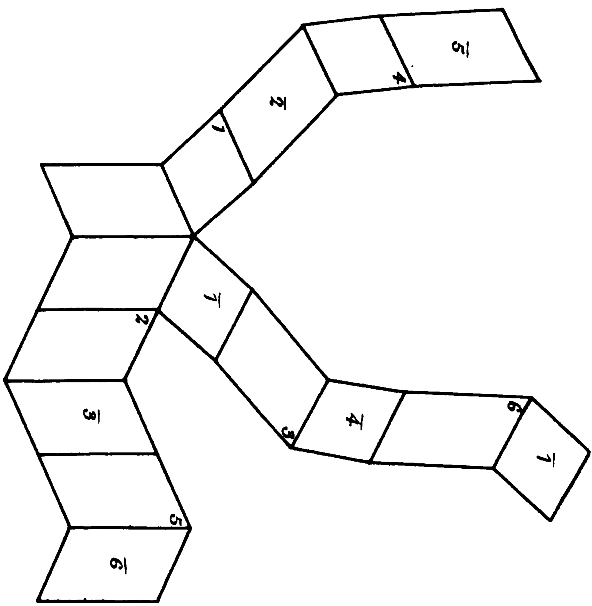
OBLIQUE RHOMBIC PRISM VAR. I. (OBLIQUITY IN LONG DIAGONAL) PLANES SAME IN BOTH VARIETIES.

Fig. 56.



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OBLIQUE RHOMBIC OCTAHEDRON AND PRISMS.

Fig. 48.

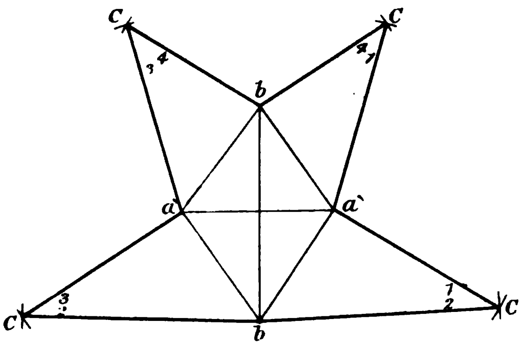
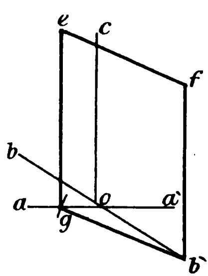


Fig. 49.



cob` 120°

E & F. N. Spon, London & New York.

Take compasses, and with radius *a c* describe the arc *a c*, Fig. 48, and with radius *b c*, Fig. 49, describe the arc *b c*, Fig. 48. The two arcs shall cut in *c*, and the triangle *a b c* is a face of the octahedron. Similarly, let the other faces be set off upon the sides of the base, and append the numbers. Of the four faces thus formed, the two upper ones are obverse and reverse to one another, and the lower ones are the same. Hence the form is contained under faces of *two* kinds only.

Oblique Rhombic Prism.—Bounded by two terminal planes which are similar rhombs, and four lateral planes which are similar rhomboids.

To find the *terminal faces*:—Let the rhomb *a b a' b'*, Fig. 48, be the terminal face.

To find the *lateral planes* (Fig. 49):—Draw *a—a'* (the first axis) at right angles to *c—o* (the third axis). Take *a b* any side of base, Fig. 48, and with one foot of compasses in *b'*, Fig. 49, draw the arc *b g*: it shall cut *a—a'* in *g*. Upon *b' g* describe the parallelogram *b' g e f*. The required *lateral plane* is the rhomboid *b' g e f*.

Of this prism there are two varieties: in the first the obliquity takes place along the *greater* diagonal of the terminal rhombs; in the second variety the obliquity occurs in the *shorter* diagonal of the terminal planes. Both are obtained by altering the adjustment of the *same* planes.

Oblique Rectangular Octahedron.—Derived from oblique rhombic octahedron. Bounded by *isosceles* triangles of two kinds and *scalene* triangles of one kind.

To find the *base*:—Bisect the side of the rhombic octahedron from which it is derived; join the bisecting points by straight lines—the rectangle *a b a' b'* is the *base* of the octahedron.

To find the *isosceles* triangles (Fig. 59):—Let *c o* (half the long axis) = 1·8 inch, cut *b—b* (the second axis) equal to 2·2 inches at an oblique angle, so that *c o b'* shall be equal to 120°.

With compasses take the distance *o a'*, Fig. 58, and with radius *o a'* describe the arc *a' b*: it shall cut *b b'* in *d*; with same radius describe the arc *a b'*: it shall cut *b b'* in *d'*. Measure *d d'*, Fig. 1, along the line *b b'*, Fig. 2.

To find the *shorter triangular face* :—Take the distance *d c*, Fig. 59, and with one foot of compasses in *b*, Fig. 58, describe the arc *b c* ; with same radius describe the arc *a' c* ; they shall cut in *c*. The *shorter triangular face* is *a' b c*.

To find the *longer triangular face* :—Take the distance *d' c*, Fig. 59, draw the arc *a c*, Fig. 58, and with same radius draw the arc *b' c* ; they shall cut in *c* ; then *a b' c* is the *longer triangle*.

To find the *scalene triangle a b c* :—Upon the side *a b* of the rectangular base, Fig. 58, and with radius equal to side *a c* of the longer triangle, set one foot of compasses in *a*, and draw the arc *a c* ; and with radius equal to side *b c* of the shorter triangle, place one foot of the compasses in *b* and draw the arc *b c* ; the two arcs shall cut in *c*, and *a b c* is the *scalene triangle*. Append the numbers to each face.

Oblique Rectangular Prism.—Bounded by rhomboid lateral planes of one kind and rectangular planes of two kinds.

To find the *lateral rhomboid face* :—With radius *a b*, Fig. 58, set one foot of compasses in *d'*, Fig. 59, and measure *d' l* along the line *b b'*. Upon *d' l* describe the parallelogram *d' l m n* ; then *d' l m n* is the *rhomboid face*.

To find the *lateral rectangular face* :—With radius *a' b*, Fig. 58, set one foot of compasses in *d'*, Fig. 59, and measure *d' g* along the line at right angles to *n d'*. Upon *d' g* describe the *lateral rectangular face d' g p n*, which was required.

To find the *terminal plane* :—Let *a b a' b'*, Fig. 58, be the *terminal plane*.

Doubly Oblique Prismatic System * (Triclinic-Anorthic).

Axes all unequal in length, and all oblique to each other.

Forms :—*Doubly Oblique Rhombic Octahedron.*

Doubly Oblique Rhombic Prism.

The Octahedron.—To find the *base* :—Let the short axis *a—a'*, equal to 1·6 inch, cut the second axis *b—b'* at an oblique angle, so that the angle *a o b* shall be equal to 100°. Join the extremities by straight lines ; then *a b a' b'* is a rhomboid, the common *base* of the two pyramids of the octahedron.

* "From their great apparent irregularity are exceedingly difficult to study and understand."—Fownes.

DOUBLY OBLIQUE RHOMBIC OCTAHEDRON AND PRISM.

Fig. 64.

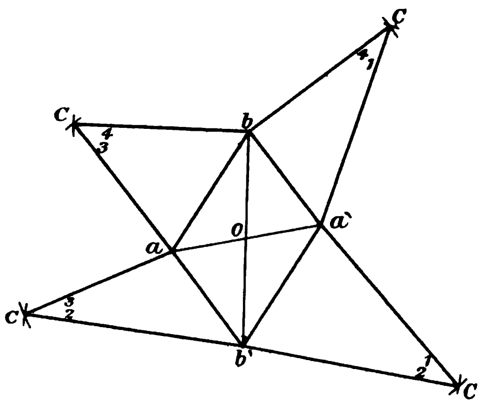
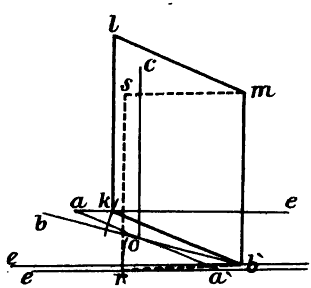


Fig. 65.



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7.

DOUBLY OBLIQUE RHOMBIC OCTAHEDRON.

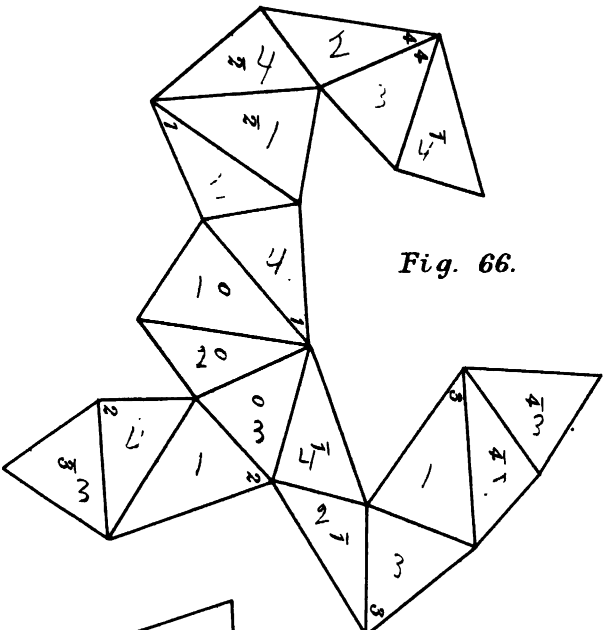

Fig. 66.

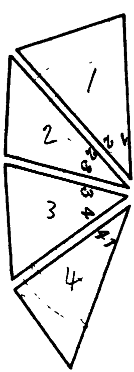

Fig. 67.

THE FOUR FACES.

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DOUBLY OBLIQUE RHOMBIC PRISM.

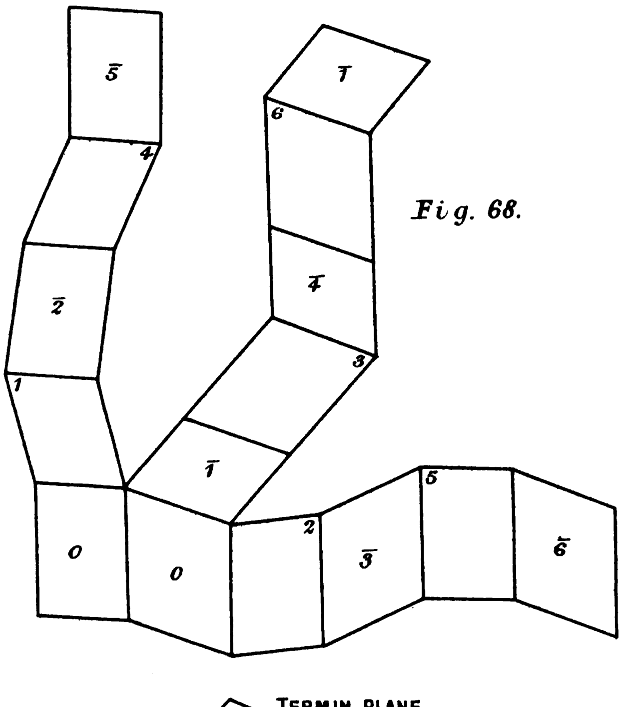
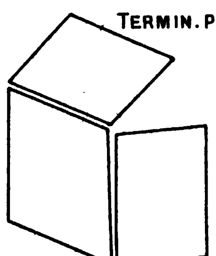


Fig. 68.

TERMIN. PLANE.



LATERAL PL: LATERAL PL:

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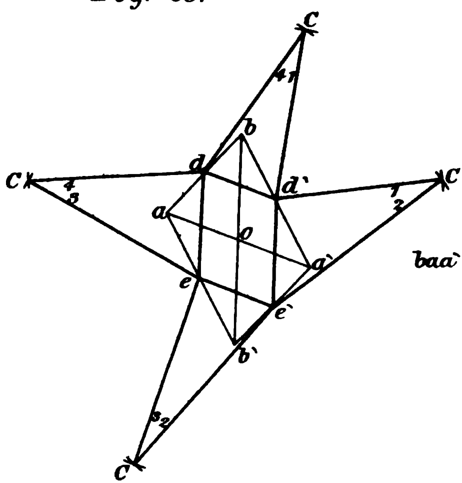
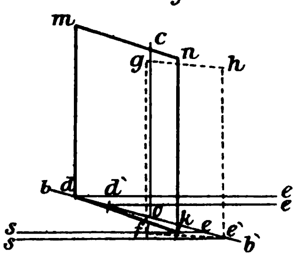
Doubly oblique derived Octahedron and Prism.

Fig. 69.



baa` 110°

Fig. 70.



cob` 105°

DOUBLY OBLIQUE OCTAHEDRON.
(QUASI RECTANGULAR)

Fig. 72.

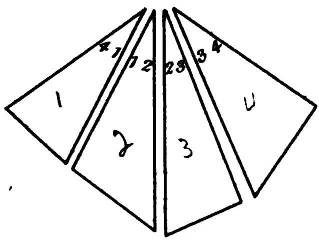
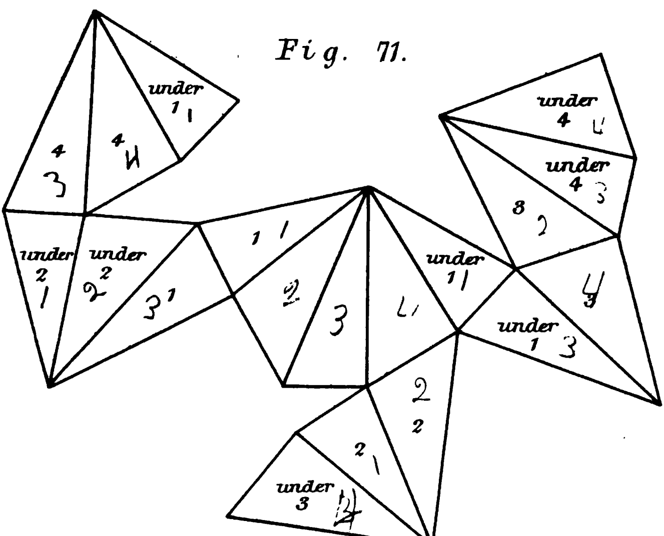


Fig. 71.



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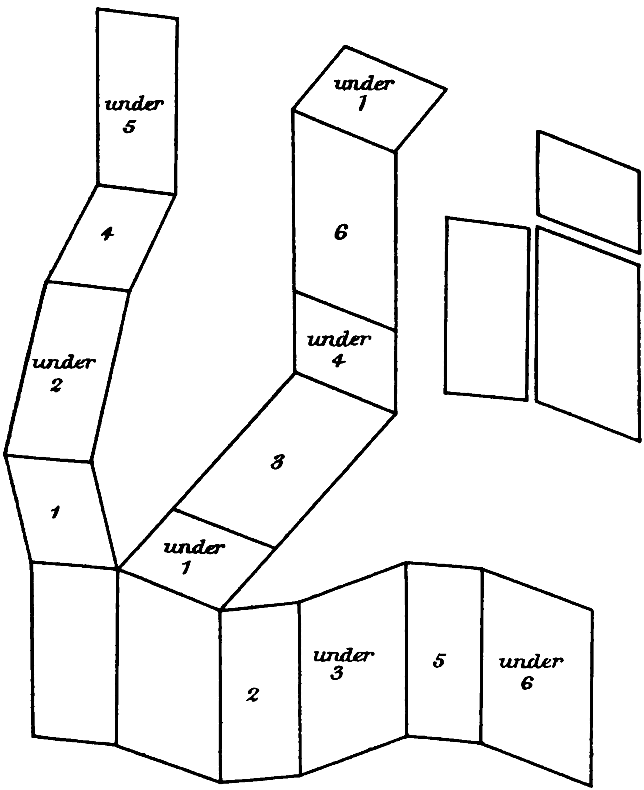
DOUBLY OBLIQUE PRISM (QUASI RECTANG:)

Fig. 73.



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To find the *triangular faces*:—Let $c\ o$, Fig. 65, be half the third axis, equal to 1·8 inch; let it be intersected in o by the short axis $a—a'$, equal to 1·6 inch, and at such an obliquity that the angle $c\ o\ a'$ shall be equal to 110°. In like manner let the second axis $b—b'$, equal to 2·2 inches, intersect, so that the angle $c\ o\ b'$ is equal to 104°.

With radius $c\ a$ place one foot of compasses in a, Fig. 64, and draw the arc $a\ c$. Take $b\ a$, Fig. 65, and draw the arc $b\ c$, Fig. 64; the two arcs shall cut in c, and the *scalene triangle* $a\ b\ c$ is one of the faces. To find a second face $a'\ b\ c$, proceed as before, the letters in both figures coinciding. The four *scalene triangles* are $a\ b\ c$, $a'\ b\ c$, $a'\ b'\ c$, and $a\ b'\ c$. Append the numbers for using the key.

The Doubly Oblique Rhombic Prism.—To find the *terminal planes*:—The base $a\ b\ a'\ b'$, Fig. 64, is one of the two terminal planes. Draw the lines $e\ a$, $e\ a'$, $e\ b'$, Fig. 65, at right angles to $c\ o'$, indicating the relative elevations of the two ends of the first axis $a\ a'$, and of the lowest end b' of axis $b\ b'$.

To find the *lateral face* $b'\ k\ l\ m$ (Fig. 65):—With radius $a\ b$, Fig. 64, and foot of compasses in b, Fig. 65, describe an arc; it shall cut the line $e\ a$ at k. Upon $b'\ k$ describe the parallelogram $b'\ k\ l\ m$, which is the rhomboid required.

To find the *lateral face* $b'\ r\ s\ m$, dotted lines (Fig. 65):—With radius $a'\ b$, Fig. 64, and one foot of compasses in b', Fig. 65, describe an arc; it shall cut $b'\ r$ in r. Upon $b'\ r$ set the parallelogram $b'\ r\ s\ m$, which is the second lateral rhomboid of the prism.

A secondary octahedron and prism belong to this system. They take the place of the *rectangular* forms in the *oblique* rhombic system.

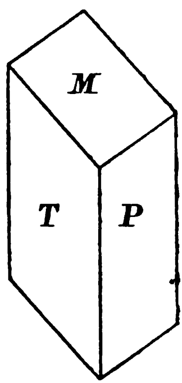
To find the *base* of the secondary octahedron (Fig. 69):—Let $a\ b\ a'\ b'$ be the base of the primary form; bisect the sides, and join the bisecting points $d\ d'\ e'\ e$ by straight lines; the rhomboid $e\ d'\ d\ e'$ is the *base* required.

To measure the distances from c of the four angles of this rhomboid along the second axis b (Fig. 70):—With one foot of compasses in o, Fig. 1, take the distance $o\ d$, and measure off

this distance *o d* along the second axis, Fig. 2. Similarly with radius *o d′*, Fig. 69, describe the arc *o d′* on the axis *b b′*, Fig. 70. In like manner set off *o e* and *o e′* on *b b′*, Fig. 70.

The four triangular faces can now be obtained :—With radius *d c*, Fig. 70, set one foot of compasses in *d*, Fig. 69, and describe the arc *d′ c*. Similarly with radius *d′ c*, Fig. 70, describe the arc *d c*, Fig. 69 ; the two arcs shall cut in *c*, and the *triangle d d′ c* is one of the four faces. Let the sides of the remaining triangles be projected in the same way. The four *scalene* faces thus found are *c d d′*, *c e′ d′*, *c e′ e*, and *c e d*. They are adjusted to make the model (see Fig. 71).

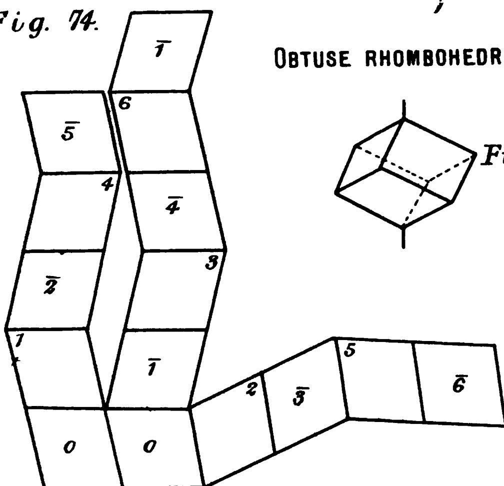
Doubly Oblique Prism.



	Edges.	°	′		Plane Angles.	°	′	″
Felspar	M on T =	120	35	..	in P =	123	29	0
	P on M =	90	0	..	in T =	104	21	0
	T on P =	67	15	..	in M =	63	18	30
Kyanite	M on T =	106	15	..	in P =	105	56	0
	P on M =	100	50	∴	in T =	100	20	30
	T on P =	93	15	..	in M =	90	15	0
Diaspore	M on T =	64	54	..	in P =	58	27	0
	P on M =	108	30	..	in T =	116	49	30
	T on P =	101	20	..	in M =	112	40	30

To find the *faces of the prism* :—Let *d e*, *d′ e′* at right angles to *c o*, Fig. 70, be the lines of elevation of the angles of the rect-

Fig. 74.



OBTUSE RHOMBOHEDRON.

Fig. 76.

ACUTE RHOMBOHEDRON.

Fig. 75.

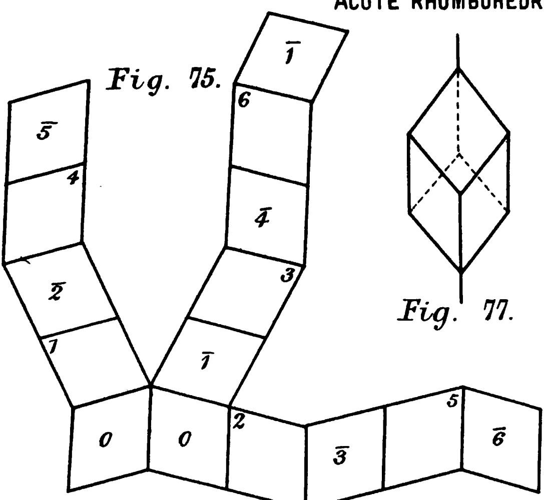


Fig. 77.

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A RHOMBIC PLANE OF 120 AND 60 THE LIMIT TO THE OBTUSE RHOMBOHEDRONS.

Fig. 78.

Fig. 79.A

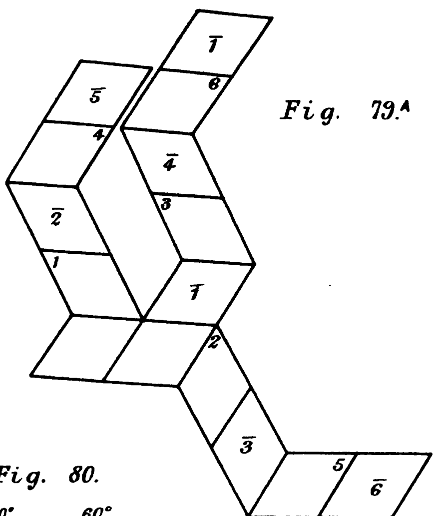
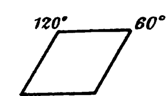


Fig. 80.



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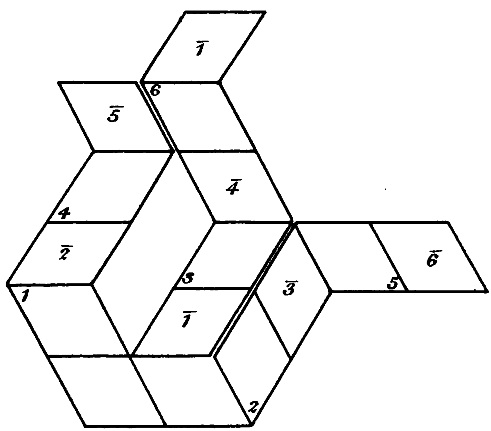
QUASI OBTUSE RHOMBOHEDRON

PLANE ANGLES OF FACES EQUAL TO 60° AND 120°.

Fig. 79.



E. &F. N. Spon, London & New York.

angular base on the upper half of the second axis *b b'*, and let *s e*, *s e'*, be the lines of elevation of the angles of the rectangle on the lower half of the same axis.

Lateral plane (α).—Take *d e*, Fig. 69, and with one foot of compasses in *d*, Fig. 70, describe the arc *d k*; it shall cut the line *s e* in *k*. Upon *d k* describe the rhomboid *k d m n*, which is the lateral plane (α) required.

Lateral plane (β).—With radius *d d'*, Fig. 69, and foot of compasses in *e'*, Fig. 70, describe the arc *e' f*, cutting the line *s e'* in *f*. Upon the dotted line *e' f* describe the rhomboid *e' f g h*, which is the lateral plane (β) required.

Terminal plane is the base *e d d' e'*, Fig. 69. For the adjustment of planes, see Fig. 73.

Rhombohedral System.

Axes three, equal in length, intersecting at an angle of 60°; the fourth perpendicular to the other three, and varying in length.

Forms:—Rhombohedron, scalenohedron, regular hexagonal prism, regular double six-sided pyramid.

1. *Rhombohedron.*—A solid, contained under six similar and equal rhombs.* These forms are of two kinds, the *obtuse* and the *acute*, the distinction arising from the structure of the solid angles of the principal axis. In the obtuse variety the solid angles are composed of three faces, the plane angles of which are greater than 90°, Fig. 76; in the acute variety the plane angles of the pyramid are less than 90°, Fig. 77.

The rhombs are adjusted in the same numerical order, and plaited like the square faces of a cube.

Obtuse Rhombohedron with the plane angles of its faces equal to 60° and 120° an impossible solid.—Let it be required to construct an obtuse rhombohedron, which shall be contained under six faces, the plane angles of which are equal to 60° and 120°. By adjusting these faces according to the key, Fig. 81, a projection like Fig. 79 is obtained. On proceeding to plait this

* A *rhomb* is that which has its four sides equal, but its angles are not right angles.

projection into the required form, it is found that by no ingenuity can it be converted into a solid. We have in fact been attempting an impossibility, which results not from any error in the process itself, but from the neglect of a self-evident geometrical truism, that "when three plane angles of 120° meet, they lie in one plane," and hence cannot form a solid angle. What actually does result, is that the figure subsides into a low, flattened pile of rhombs, arranged in the form of a hexagon, Fig. 78. This exceptional rhombohedron was noticed by Brooke.

A second method for projecting the planes of this *quasi* rhombohedron is given in Fig. 79A. It is worthy of notice; for while in its present state it refuses to assume the form of a solid, yet, by simply *creasing its rhombic faces in their short diagonal*, it becomes at once converted into the *regular octahedron*, Fig. 17, which see.

Mode of Using the Key.

Describe a face of any given rhombohedron, Fig. 82, cut it out in cardboard for a pattern, and draw a line across its long diagonal.

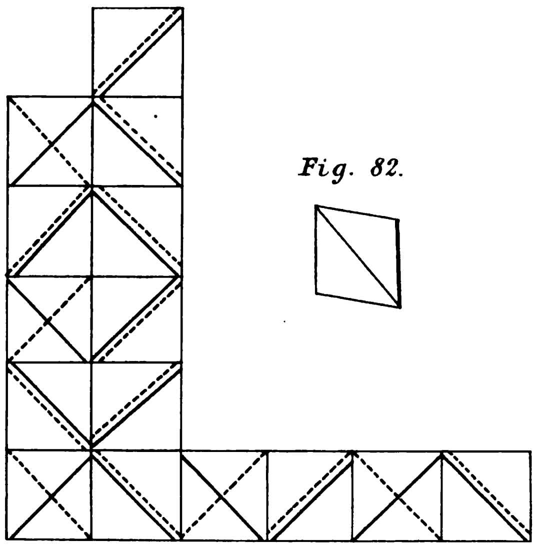
Next trace on a sheet of paper successive outlines of the pattern, so that the directions of its diagonals shall correspond with those of the key. When the direction of the *dotted* lines in the key is followed, the model will be an *obtuse rhombohedron;* but when the long diagonal of the pattern corresponds with *continuous* lines on the key, the model is *acute*.

Two distinct forms are thus seen to be produced from one and the same plane by the mere shifting of its sides: it follows that it is not a matter of indifference as to which pair of sides shall meet to form an edge; and, moreover, that, while the process of plaiting determines the relative position of all the faces themselves, it does not locate that of the sides of those faces. Hence the necessity for some simple expedient like that which has been here adopted.

Acute Rhombohedron of Carbonate of Iron.—This solid has two of the faces of an acute pyramid inclined to each other at their edge, at an angle of 67° 20′. (Phillips.)

KEY FOR ADJUSTING THE PLANES OF ALL THE RHOMBOHEDRONS.

Fig. 81.



Acute ————

Obtuse - - - - - - -

Fig. 82.

Fig. 83.

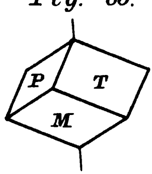
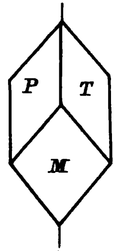


Fig. 84.



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To find the plane angles of a face:—

$$\text{Log.} \frac{1}{2 \sin \frac{1}{2} A} = \cos \tfrac{1}{2} a.$$

$$\text{Let } A = 67° \ 20'.$$

$$\tfrac{1}{2} A = 33° \ 40'.$$

$$L \sin \tfrac{1}{2} A = 9 \cdot 7437921.$$

$$L \ 2 \sin \tfrac{1}{2} A = 10 \cdot 0448221.$$

$$L \frac{1}{2 \sin \frac{1}{2} A} = 9 \cdot 9551779 \cdot$$

Hence,

$\cos \frac{1}{2} A = 25° \ 36' \ 85''$

$\therefore A = 50° \ 73' \ 70''$ = the plane acute angles of the rhomb.

The plane angles of the rhomb, therefore, are equal to

$50° \ 73' \ 70''$

$128° \ 45' \ 50''$.

To make the figure, the planes are adjusted as in the projection, Fig. 75. See Key.

Obtuse Rhombohedron.

$$\left(\cos \tfrac{1}{2} A = L \frac{1}{2 \sin \frac{1}{2} E}\right)$$

Inclination of faces at edges.	° ′		° ′	Plane angles of faces = ° ′	° ′
P on T =	92 50	..P on M =	87 10	92 42	87 18
	94 15		85 45	93 57	86 3
	94 46		86 14	94 24	85 36
	105 5		74 55	101 55	78 5
	106 15		73 45	102 38	77 22
	107 20		72 40	103 16	76 44
	106 30		73 30	102 47	77 13
	107 0		73 0	103 5	76 55
	108 30		71 30	103 56	76 4
	126 17		54 43	111 50	68 10
	133 50		46 10	114 9	65 51

Acute Rhombohedron.

$$\left(\cos \tfrac{1}{2} A = L \frac{1}{2 \sin \frac{1}{2} E}\right)$$

Inclination of faces at edges.	° ′		° ′	Plane angles of faces = ° ′	° ′
P on M =	93 56	..P on T =	86 4	94 14	85 46
	107 30		72 30	115 28	64 32
	109 28		70 32	120 - 1	60 0

Scalenohedron.—The plane angles of a face of the obtuse rhombohedron of calcite given, to find the scalene triangular face of the scalenohedron.

First, find the *principal axis* of the rhombohedron:—Let Fig. 85 be a rhomb with plane angles equal to 101° 54′ 50″, and let A C be its long diagonal, and B D its short one.

With any side A B, Fig. 85, describe the equilateral triangle E F G, Fig. 86; and let O be its centre.

Produce (Fig. 87) the straight line A X, on which to find the principal axis; and with radius equal to side A B, Fig. 85, describe the arc *c c*, Fig. 87.

Take the line G O, Fig. 86, and set it at right angles at some point along the line A X; it will be found to cut the arc *c c* in B. Then A B, Fig. 87, is equal to a side of the rhomb; B C is equal to its short diagonal; while A C is the *principal* axis.

To make the *scalene triangle* of the scalenohedron:—Produce the line A C, Fig. 87, to S, so that A S is equal to the axis A C. Complete by dotted lines the parallelogram A B C E, and make the *scalene triangle*, Fig. 88:—

A B = S E, Fig. 87,
A C = S B, „ „
B C = B C, „ 85.

Double Six-sided Pyramid.—Bounded by twelve equal and similar *isosceles triangles.*

Like the scalenohedron, and belonging to the same system, it is made by joining two of the faces together by their sides, and treating the *trapezium* thus formed as if it were a *rhomb.* Counting two planes as one, they are then adjusted as if for a rhombohedron, numbered in the same order, and made up into a model with the same facility. (Fig. 93A.)

Hexagonal Prism.—Contained under eight faces—six lateral *rectangles*, and two terminal *hexagons.* Inclination of lateral on terminal planes equal to 90°; inclination of lateral planes equal to 120°.

Instead of using eight planes, it is far more convenient to

Fig. 85.

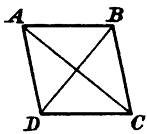


Fig. 86.

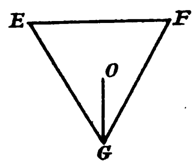


Fig. 87

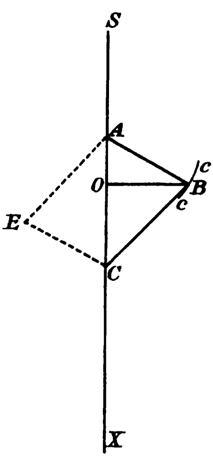
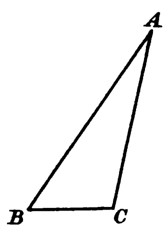


Fig. 88.



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SCALENOHEDRON.

Fig. 89.

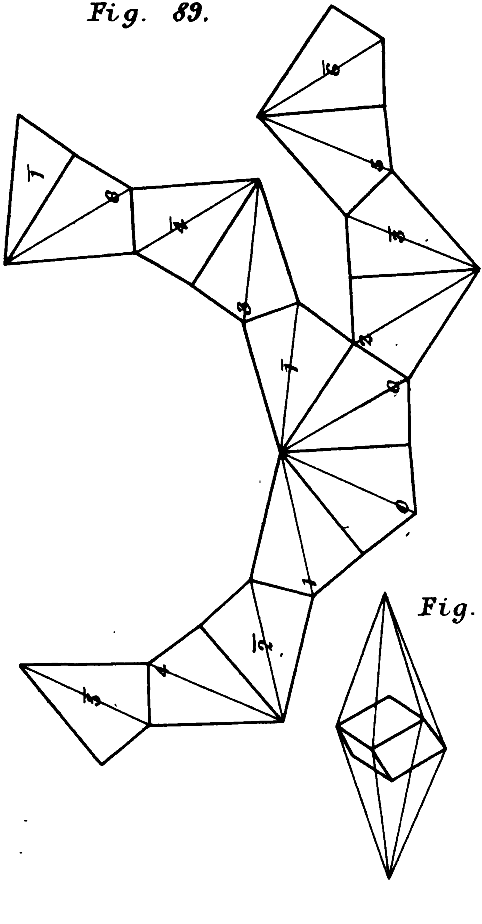

Fig. 89.a

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HALF SCALENOHEDRON AND HALF RHOMBOHEDRON OF CALCITE IN ONE MODEL.

Fig. 90.

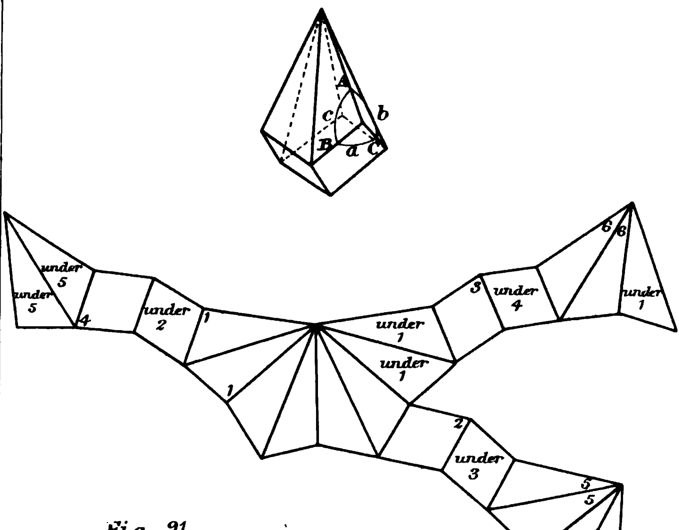
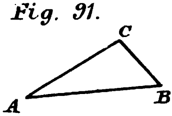
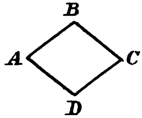


Fig. 91.



A = 25° 21′
B = 52° 18′ 39″
C = 102° 20′ 21″

Fig. 92.



B = 101° 55

DOUBLE SIX-SIDED PYRAMID.

Fig. 93.

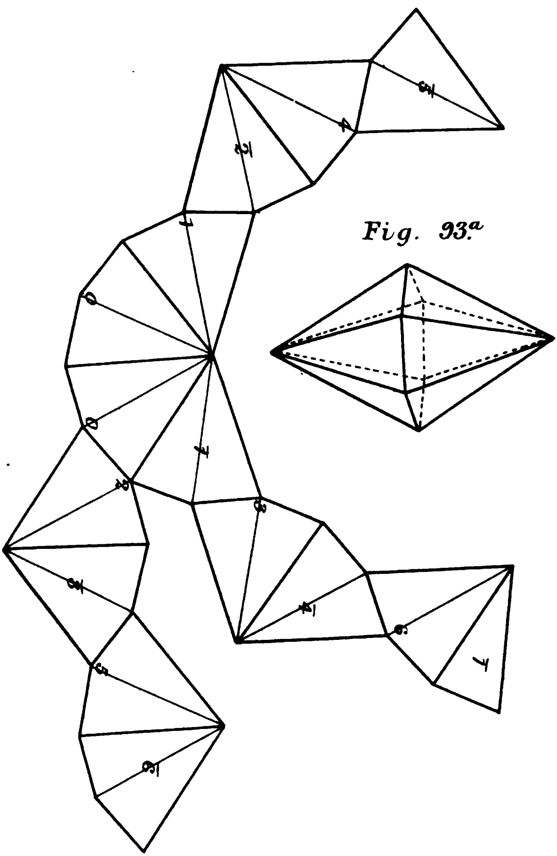


Fig. 93.a

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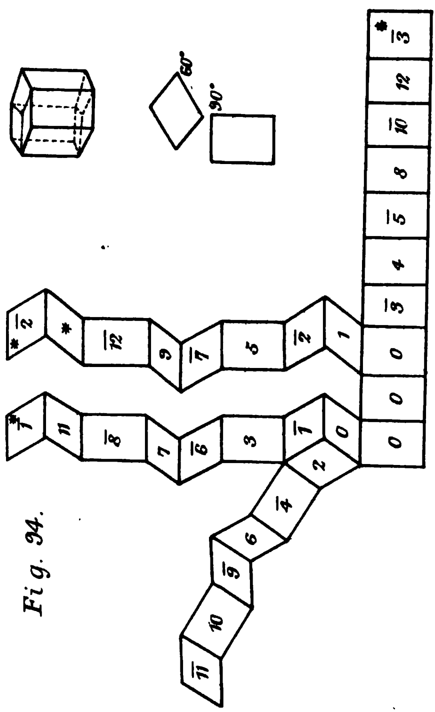
HEXAGONAL PRISM.

Fig. 95.

Fig. 94.



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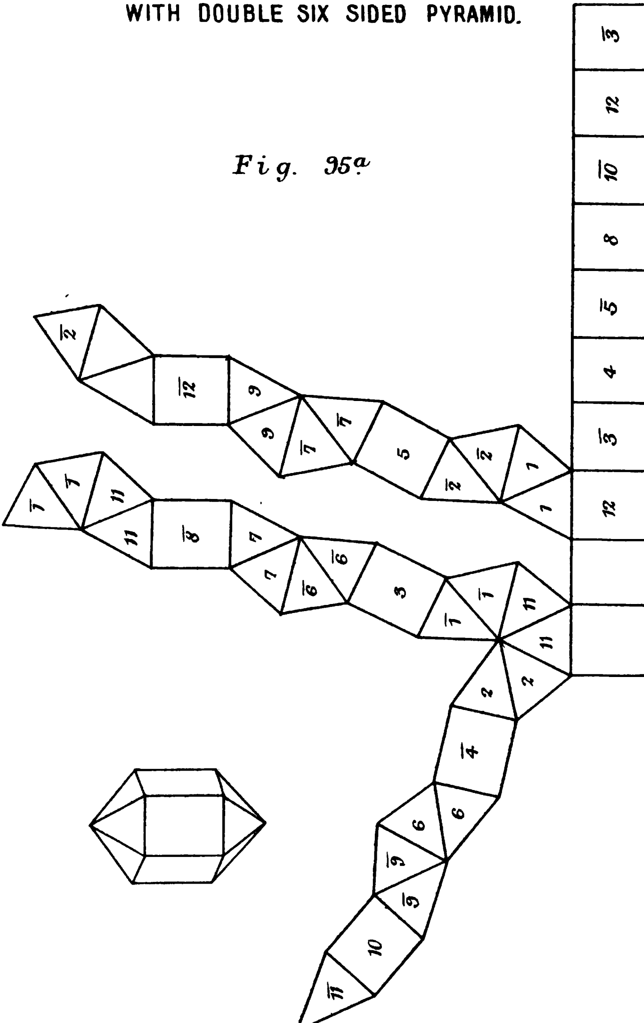
HEXAGONAL PRISM WITH DOUBLE SIX SIDED PYRAMID.

Fig. 95a.



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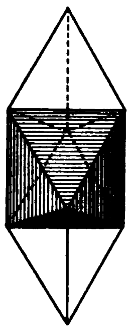
ACUTE RHOMBOHEDRON.

Fig. 96.



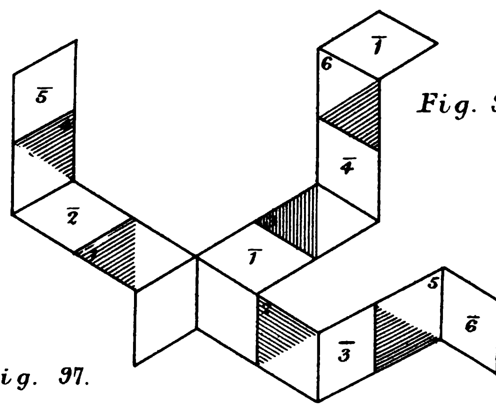
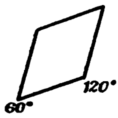


Fig. 98.

Fig. 97.



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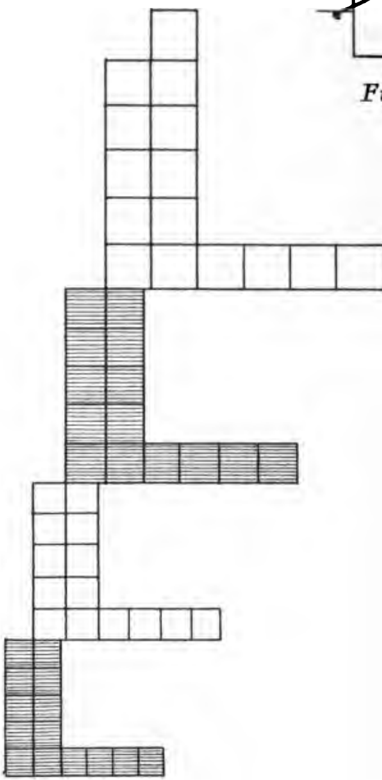
CUBE GROWTH.

Fig. 99.



The three cleavages of Iron pyrites.

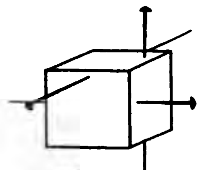


Fig. 100.

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resolve each terminal hexagon into three rhombs, the plane angles of which are equal to 60° and 120°. The model can now be made by adjusting the planes as in Fig. 94. It will be found to be contained under twelve faces, viz. three rhombs composing each terminal plane, and six rectangles—making twelve in all. By using the type composed of four fillets (Fig. 94), we obtain the model itself in a compact and stable form, but its terminal hexagons present a mosaic of three pieces, all lying in one plane. We may now call a model thus constructed a *typical* hexagonal prism, inasmuch as by altering the plane angles of the rhombs, pyramids of three and six sides can be raised on its ends, forming modifications which imitate natural crystals, as of quartz, &c. (See Fig. 95A.)

Acute Rhombohedron containing a nucleated *regular octahedron* (Fig. 96):—Let the plane angles of the rhomb, Fig. 97, be equal to 60° and 120°. Make the plane projection, Fig. 98, and shade the faces as in the figure. When the model is completed, the *octahedron* will appear as shown in Fig. 96.

Crystal Growth; Cleavage.

Besides mere hollow models, the plaiting process enables us to insert a number of similar forms of *different sizes*, one within the other, so as to resemble real solids composed of concentric layers.

A model made by enclosing cube within cube resembles a real crystal more nearly than one which displays its faces only. It is strikingly suggestive of the mode adopted in the natural growth of a crystal, in its cleavage, and in other structural peculiarities. Crystals are conceived to increase in magnitude by the continual addition of plates of molecules to their surfaces.

The structure of crystals in the order in which their molecules are arranged may be illustrated by an experiment with common salt. If a portion of this salt be dissolved in water, and the water be allowed to evaporate slowly, rectangular crystals will be developed, deposited on the sides and bottom of the vessel. These will at first be very minute, but they will

increase in size as the evaporation proceeds; and if the quantity of salt dissolved be sufficient, they will at length attain a considerable magnitude.

If the edge of a knife be applied to the surface of any one of these crystals in a direction parallel to one of its edges, the crystal may, by a slight blow, be cleaved parallel to one of its sides.

It is hence inferred that the molecules of crystals are so arranged as to form plates in the direction of all their primary planes.

This peculiarity in crystal structure is well exemplified in the model, Fig. 100, which is supposed to consist of a series of cubes, small at first, but gradually enlarging from the centre. A model thus constructed will permit of needles being thrust through its entire thickness in directions *parallel to its sides*, but in no other directions.

Parallel markings in straight lines are found on the surfaces of many natural crystals. These are called *striæ* (from the Latin word *stria*, a groove or channel). They are often seen in the cubes of *iron pyrites*. The *striæ* on any given face being always perpendicular to those on its adjacent faces (Fig. 106). This character can be imparted to a model with the greatest ease by drawing parallel lines longitudinally along each fillet (Fig. 105), which will so intersect in plaiting that the model will become an exact fac-simile of the natural crystal (Fig. 106).

These results are suggestive of the primordial arrangement of the molecules in crystal forms. What, for instance, should hinder the particles, when starting into activity, from aggregating themselves into three distinct infinitesimally thin laminæ? destined to grow in three zones; and further, that each zone shall be endued with a force compelling it to bend at a right angle at given intervals, and that these zones shall overlap one another after the manner of a plait, thus forming a minute cubic crystal. The same forces continuing to act, this minute crystal *may* constitute the nucleus around which hundreds—nay, thousands—of fresh laminæ shall develop themselves, each forming a fresh nucleus to the next outer one, until finally the entire form shall consist of an almost innumer-

RHOMBOHEDRON GROWTH.

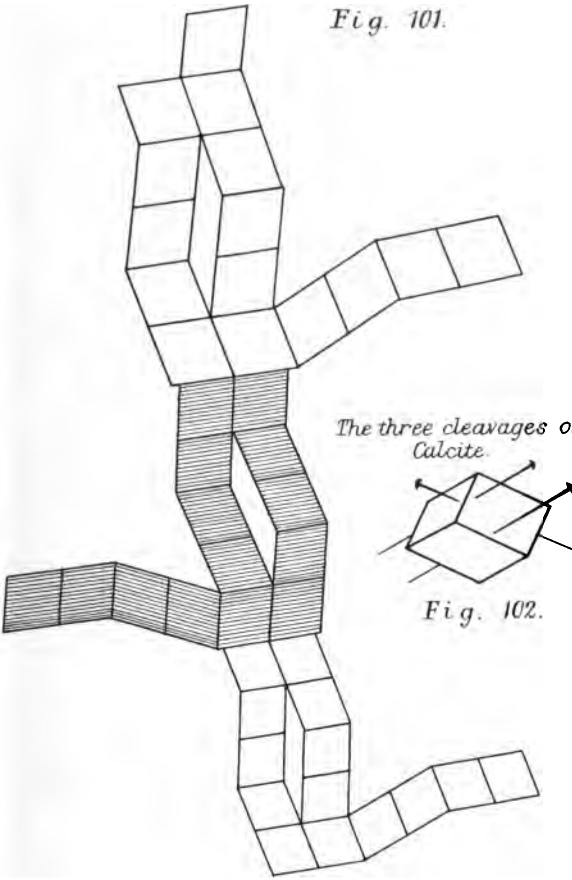

Fig. 101.

The three cleavages of Calcite.

Fig. 102.

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OCTAHEDRON GROWTH.

The 4 cleavages of Oxydulated Iron or Native Loadstone.

Fig. 103.

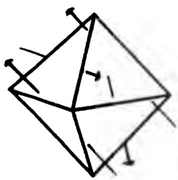
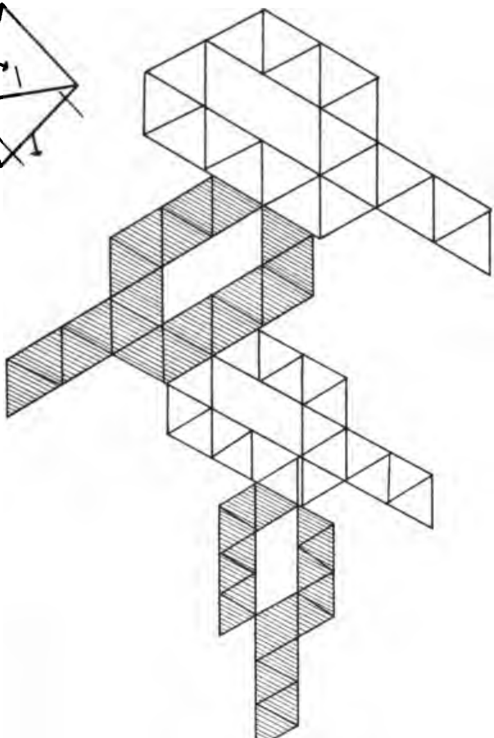


Fig. 104.



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DIRECTIONS *of striation reproduced when longitudinal striæ are made on each strip and then plaited into a model.*

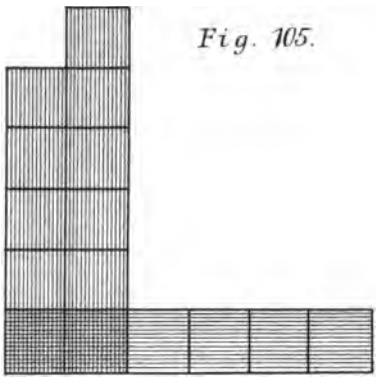

Fig. 105.

CUBE OF IRON PYRITES. *Striæ of adjacent faces perpendicular to each other.*

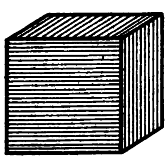

Fig. 106.

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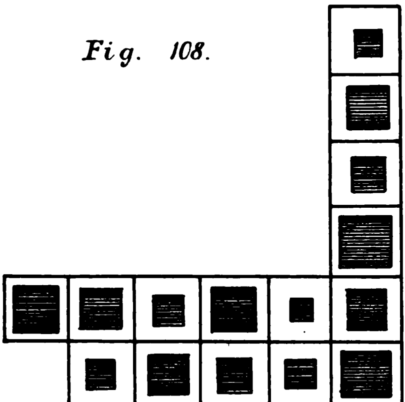
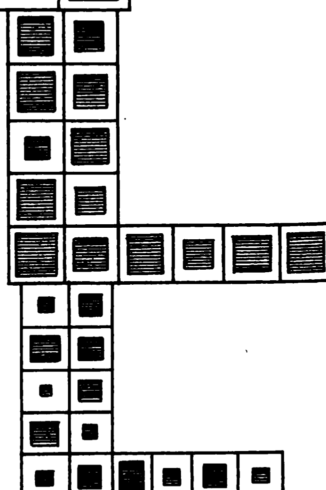
CRYSTAL OF BISMUTH.

Fig. 108.





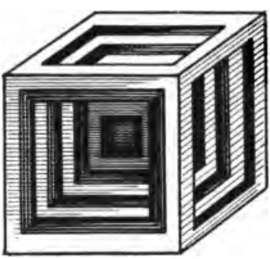


Fig. 107.

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able series of hollow cubes, so closely packed as to become virtually a solid.

On this hypothesis the *cleavage* property of a crystal becomes almost a necessary result; the natural joints or intervals of disintegration consisting of the spaces between the nucleated forms of which the crystal is constructed.

Of Crystals of Bismuth and of Bromide and Iodide of Potassium.—It is not usual for crystal forms to disclose to view any part of their structure, excepting that which lies directly on their surface. An opportunity is seldom afforded, therefore, of obtaining a survey of their interior. Hence the initial direction in which the particles are propelled by their respective forces, in order to build up a crystal, is for the most part a mere matter of conjecture. Some remarkable exceptions do occur, however, in certain crystals where nearly the entire face, excepting only a narrow margin near the edge, is absent. These deficiencies are seen to be replaced by deep excavations which frequently descend almost to the centre. Examples of this peculiarity in structure are afforded in the slowly cooled crystals of *bismuth* and in crystals of the *bromide* and *iodide* of *potassium*. The hollows above noticed present the appearance of four-sided pyramids, their apices pointing inwards towards the centre. They appear to consist of a series of square frames piled up one upon the other, and growing sensibly and abruptly bigger from within outwards; they become graduated, so that each side of the pyramid assumes the appearance of a miniature flight of steps.

From the facilities afforded by the plaiting process for constructing a nucleated model of the cube, it appeared not improbable that by substituting square *frames* for square *faces*, as shown in Fig. 108, models of these beautiful crystals might be made, and if so, that a clue would be thus obtained as to the mysterious process adopted by nature in the formation of structures at once so intricate and incomprehensible.

The resulting model with its projection are shown in the figures.

Even solid crystals, if transparent, may sometimes present certain markings which are suggestive of their development.

In some specimens of *uric acid* it was noticed by Dr. Golding Bird, that under the microscope "*they appeared nucleated from the presence of certain internal markings, as if one crystal included another;*" and again, that "*when the rhombic outline of the crystal is replaced by a square one, in such crystals an internal marking like a frame-work is visible.*"

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